APPLICATION OF A PARAMETER-ESTIMATION TECHNIQUE TO MODELING THE REGIONAL AQUIFER UNDERLYING THE EASTERN SNAKE RIVER PLAIN, IDAHO

By S. P. Garabedian

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WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information, write to:

Idaho Office Chief
U.S. Geological Survey, WRD
230 Collins Road
Boise, ID 83702
(208) 334-1750

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CONTENTS

	Page
Abstract	1
Introduction	2
Location and description of study area	2
Previous investigations	2
Acknowledgments	4
Geology of the eastern Snake River Plain	4
Ground-water hydrology	10
Recharge	12
Discharge	22
Water budget	22
Ground-water flow model	25
Application of ground-water flow model to the eastern Snake River Plain regional aquifer	29
Model grid and boundary conditions	31
Model assumptions	32
Model calibration	33
Comparison of simulations	37
Comparison with previous studies	47
Summary and conclusions	49
References	51

APPENDIXES

APPENDIX A.	Diversion and return-flow data for water year 1980	54
B.	Parameter estimation program documentation	69
C.	Modified parameter estimation program	84

PLATES

[In pocket, back of report]

PLATE 1. Configuration of the water table, 1928-30, 1956-58, and March 1980; and water-level hydrographs of selected wells, eastern Snake River Plain, Idaho

2. Ground-water flow model grid, aquifer zones, leakage blocks, and boundary flux, eastern Snake River Plain, Idaho

3. Configuration of the water table, March 1980, compared with configuration based on model-calculated heads, eastern Snake River Plain, Idaho

ILLUSTRATIONS

		Page
FIGURES 1-3.	Maps showing:	
	1. Well-numbering system	VIII
	2. Location of study area	3
	3. Generalized geology	6
4.	Diagram showing hydrogeologic section A-A'	8
5.	Diagram showing hydrogeologic section B-B'	9
6.	Graph showing mean annual ground-water flow to the Snake River from north-side springs between Milner and King Hill	11
7.	Graph showing total diversions for irrigation on the eastern Snake River Plain, water years 1928-80, from the Teton, Fall, Henrys Fork, Snake, and Blackfoot Rivers	13
8-10.	Maps showing:	
	8. Irrigated lands in 1979	14
	9. Distribution of generalized soil types	21
	10. Water-level changes in the regional aquifer, October 1979 to October 1980	24
11-13.	Diagrams showing:	
	11. Example of aquifer zonation	27
	12. Finite-difference, mesh-centered grid notation	28
	13. Notation for head interpolation	30
14.	Graph showing model-run standard errors of estimates	35

TABLES

TABLE 1.	Estimated recharge rates for irrigated areas in 1980	16
2.	Snake River losses to and gains from ground water in water year 1980	17
3.	Tributary stream and canal losses to aquifers based on various periods of record	18
4.	Tributary valley underflow based on basin-yield equations	19
5.	Estimated recharge from precipitation	20
6.	Aquifer budget, water year 1980	23
7.	Regression parameters for simulations 40, 42, 46-50	38

TABLES--Continued

		Page
TABLE 8.	Statistical results for simulations 40, 42, 46-50	39
9.	Comparison of model-calculated and measured spring discharge	40
10.	Transmissivity values for simulations 40, 42, 46-50	41
11.	Mass-balance calculations for simulations 40, 42, 46-50	42
12.	Scaled sensitivities for simulation 49	46
13.	Comparison of transmissivity values with previous studies	48

CONVERSION FACTORS

For the convenience of those who prefer to use International System (SI) units rather than inch-pound units, conversion factors for items used in this report are listed below.

Multiply inch-pound unit	By	To obtain SI unit
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot squared per second (ft^2/s)	0.0929	meter squared per second
inch (in.)	25.40	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Well-Numbering System

The well-numbering system (fig. 1) used by the U.S. Geological Survey in Idaho indicates the location of wells within the official rectangular subdivision of public lands, with reference to the Boise base line and meridian. The first two segments of the number designate the township (north or south) and range (east or west). The third segment gives the section number, followed by three letters and a numeral, which indicate the ¼ section (160-acre tract), ¼-¼ section (40-acre tract), ¼-¼-¼ section (10-acre tract), and serial number of the well within the tract.

Quarter sections are designated the letters A, B, C, and D in counterclockwise order from the northeast quarter of each section. Within quarter sections, 40-acre and 10-acre tracts are lettered in the same manner. For example, well 8S-19E-5DAB1 is in the SE¼NE¼NW¼ sec. 5, T. 8 S., R. 19 E., and is the first well inventoried in that tract.

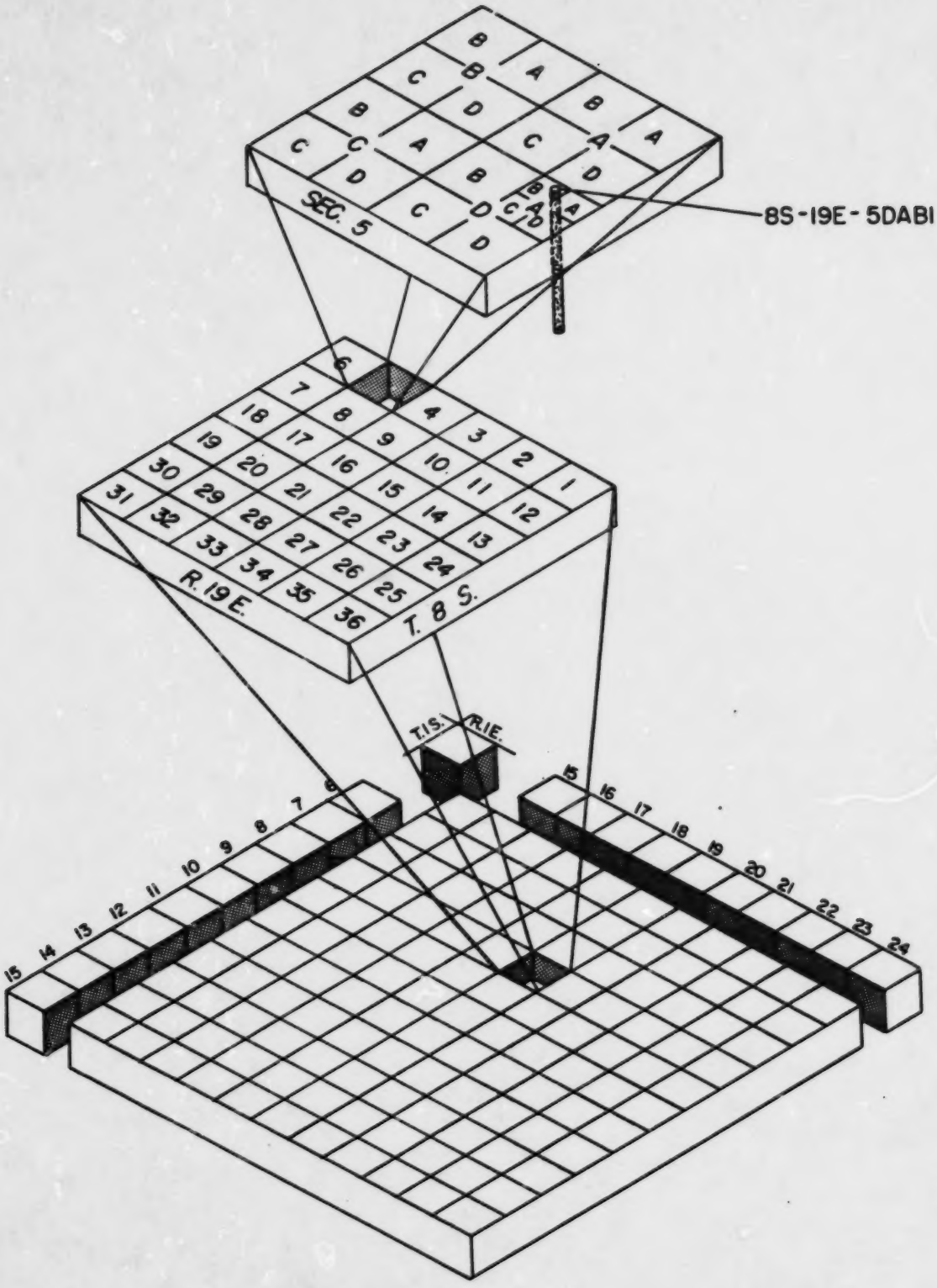

Figure 1.--Well-numbering system.

APPLICATION OF A PARAMETER-ESTIMATION TECHNIQUE TO MODELING THE REGIONAL AQUIFER UNDERLYING THE EASTERN SNAKE RIVER PLAIN, IDAHO

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ABSTRACT

A nonlinear, least-squares regression technique for the estimation of ground-water flow model parameters was applied to the regional aquifer underlying the eastern Snake River Plain, Idaho. The computer program simulates two-dimensional, steady-state ground-water flow. Hydrologic data for the 1980 water year were used to calculate recharge rates, boundary fluxes, and spring discharges. Ground-water use was estimated from irrigated land maps and crop consumptive-use figures. These estimates of ground-water withdrawal, recharge rates, and boundary flux, along with leakance, were used as known values in the model calibration of transmissivity. Leakance values were adjusted between regression solutions by comparing model-calculated to measured spring discharges. In other simulations, recharge and leakance also were calibrated as prior information regression parameters, which limits the variation of these parameters using a normalized standard error of estimate.

Results from a best-fit model indicate a wide areal range in transmissivity from about 0.05 to 44 feet squared per second and in leakance from about 2.2×10^{-9} to 6.0×10^{-8} feet per second per foot. Along with parameter values, model statistics also were calculated, including the coefficient of correlation between computed and observed head (0.996), standard error of the estimates of head (40 feet), and parameter coefficients of variation (about 10-40 percent). Additional boundary flux was added in some areas during calibration to achieve proper fit to ground-water flow directions. Model fit improved significantly when areas that violated model assumptions were removed. Model fit also improved when y-direction (northwest-southeast) transmissivity values were larger than x-direction (northeast-southwest) transmissivity values. The model was most sensitive to changes in recharge, and in some areas, to changes in transmissivity, particularly near the spring discharge area from Milner to King Hill.

INTRODUCTION

This report is one in a series resulting from the U.S. Geological Survey Snake River Plain RASA (Regional Aquifer-Systems Analysis) study that was initiated in October 1979.

As stated by Lindholm (1981), purposes of the study were to (1) refine knowledge of the regional ground-water flow system, (2) determine effects of conjunctive use of ground and surface water, and (3) describe solute chemistry.

This report presents a refinement in knowledge of the regional ground-water flow system. A two-dimensional, steady-state ground-water flow model was used to develop preliminary estimates of transmissivity, leakance, and boundary fluxes for the regional aquifer underlying the eastern Snake River Plain. Estimates of aquifer recharge and discharge during water year 1980 were made as a basis for calibrating the unknown parameters: transmissivity, leakance, and some boundary fluxes.

Location and Description of Study Area

The eastern Snake River Plain is part of the arcuate Snake River Plain that extends across southern Idaho into Oregon (fig. 2). The eastern plain is about 170 mi long, 60 mi wide, and 10,800 mi^2 in area. Altitudes range from about 2,500 ft above sea level at river level near King Hill to about 6,000 ft in the northeastern part of the plain. The surrounding mountains rise 7,000-12,000 ft in altitude. The eastern plain is entirely within the Snake River drainage basin. Streams in several tributary intermontane valleys lose all flow to infiltration or evaporation after reaching the plain.

The eastern Snake River Plain is underlain chiefly by basalt, which transmits large volumes of water and is a major regional aquifer in southern Idaho. Discharge from the aquifer is largely spring flow, which sustains [illegible] part of streamflow in the Snake River. The basaltic aquifer is a major source of irrigation water. Most crops grown on the eastern plain are irrigated because annual precipitation over most of the area is only about 8-10 in.

Previous Investigations

Numerous studies and reports have been made of geology and ground-water resources of the eastern Snake River Plain. Notable early studies were made by Russell (1902) and Stearns and others (1938). A quantitative hydrologic study by Mundorff and others (1964) included

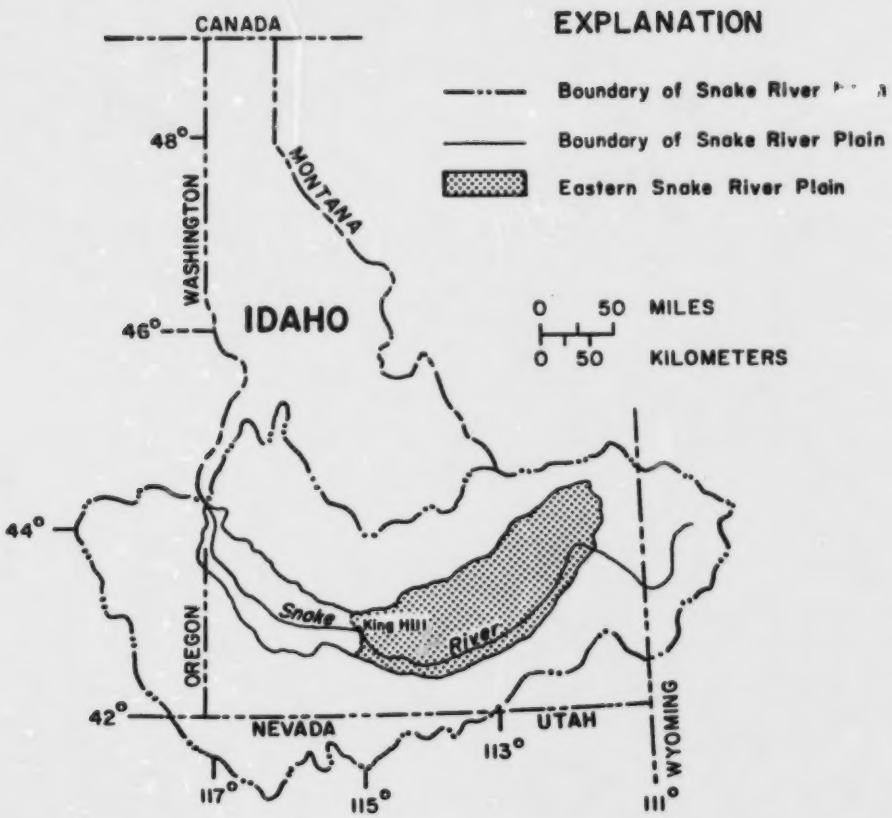

Figure 2.--Location of study area.

estimates of transmissivity by use of a flow-net analysis. Electric analog model studies of the regional aquifer underlying the eastern plain were made by Skibitzke and da Costa (1962), Norvitch and others (1969), and Mantei (1974). Numerical model studies were made by deSonneville (1974), Newton (1978), and Wytzes (1980). Solute-transport modeling of radioactive wastes at the Idaho National Engineering Laboratory was done by Robertson (1974, 1977).

Acknowledgments

The author wishes to thank Richard L. Cooley and Aldo V. Veechia of the U.S. Geological Survey for their suggestions and error analysis which helped to improve the report.

GEOLOGY OF THE EASTERN SNAKE RIVER PLAIN

The predominant rock type of the eastern Snake River Plain is Quaternary basalt (fig. 3). Basalt, interbedded with terrestrial sediments, fills a structural basin bounded by faulting on the northwest and downwarping and faulting on the southeast (Whitehead, 1984). The northeastern end of the plain is defined by silicic volcanic rocks (mainly rhyolite), which also occur southwest of the plain. Granitic rocks and pre-Cretaceous sedimentary and metamorphic rocks occur northwest of the plain. Adjacent and perpendicular to the axis of the plain are several intermontane valleys characterized by basin and range structure. Kuntz (1978) noted that volcanism on the eastern plain is localized along rift zones (fig. 3). Rifts appear to be extensions of basin and range faults that occur in areas surrounding the plain. Kuntz (1978) indicated that faults are abundant owing to extension in the northeast-southwest direction along the axis of the eastern plain. In some places, this extension has caused open fissures at land surface.

Quaternary basalts were extruded from individual vents or series of vents and individual flows are thin, averaging 20-25 ft in thickness. Aggregate basalt thickness may, in places, exceed several thousand feet, as shown in figures 4 and 5 (Whitehead, 1984). Individual flows are of variable areal extent, commonly 50-100 mi^2. Sediments interbedded with the basalt along the edges of the plain were deposited by the Snake River and tributary streams (figs. 4 and 5). In some areas, particularly in alluvial fans, sand and gravel predominate. In other areas, particularly where streams were dammed by basalt flows, silt and clay are the predominant sediments. Along some margins of the plain and possibly under the entire eastern plain, rhyolite underlies the basalt.

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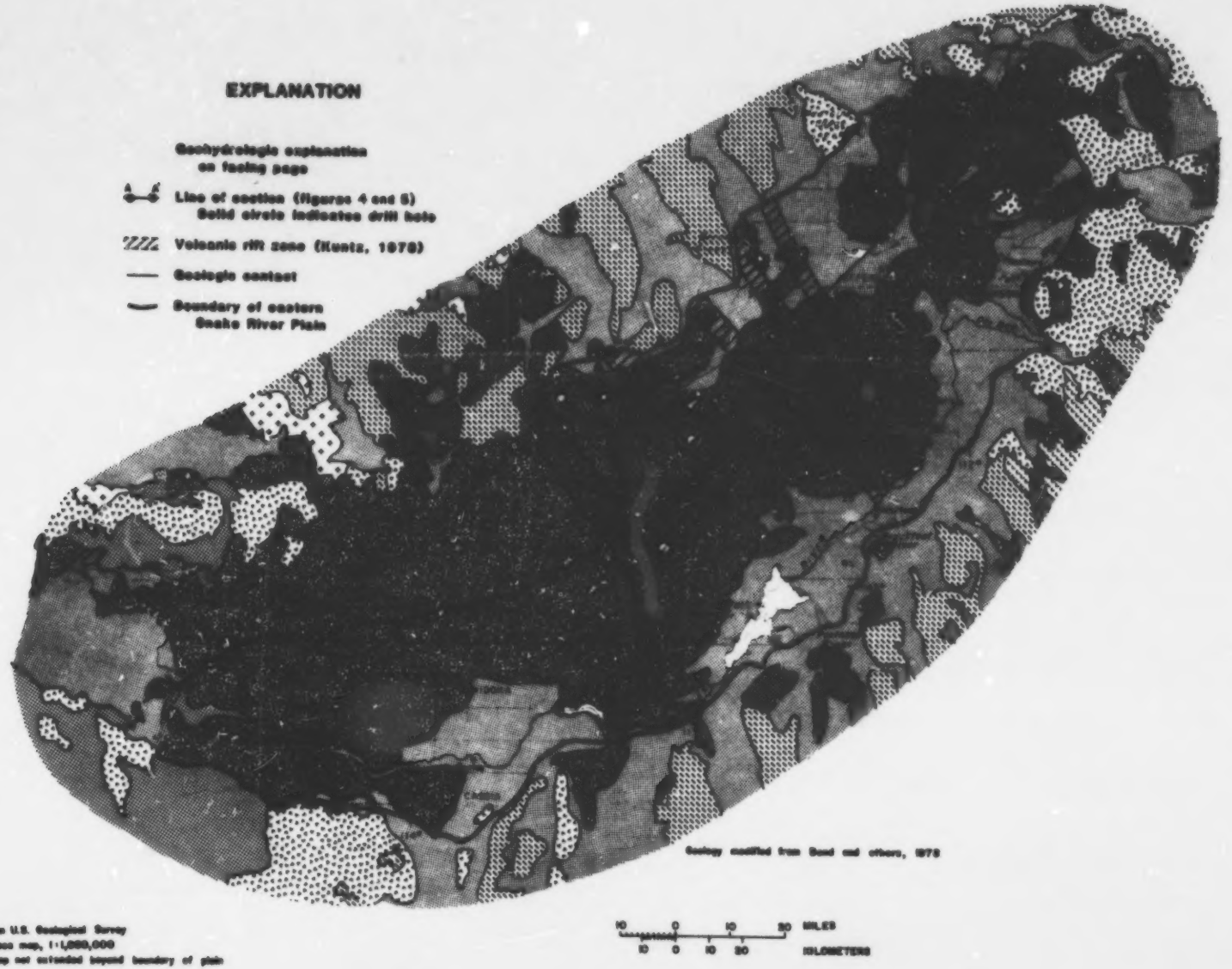
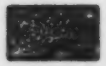
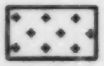

EXPLANATION
Geohydrologic explanation on facing page
Line of section (figures 4 and 5) Solid circle indicates drill hole
Volcanic rift zone (Kuntz, 1978)
Geologic contact
Boundary of eastern Snake River Plain
Geology modified from Bond and others, 1978
Base from U.S. Geological Survey
State base map, 1:1,000,000
State map not extended beyond boundary of plain
10 0 10 20 MILES
10 0 10 20 KILOMETERS

Figure 3.—Generalized geology.

CORRELATION AND DESCRIPTION OF GEOLOGIC UNITS

Age	Map symbol	Lithologic characteristics	Hydrologic characteristics
Quaternary and late Tertiary		Sedimentary rock, unconsolidated to poorly consolidated; includes colluvium and flood-plain, glacial, eolian, and lake deposits. Size ranges from clay to gravel. Minor interbedded volcanics.	Sand and gravel alluvium yields moderate to large quantities of water. An important aquifer. Eolian deposits generally unsaturated. Finer-grained deposits impede vertical flow and cause local shallow water-table conditions. Older alluvium includes sand and gravel zones that are important local aquifers.
Quaternary and late Tertiary		Basaltic rock composed of olivine basalt, basaltic cinders, and minor interbedded sediments. Irregular to columnar jointing.	Primary unit of the eastern Snake River Plain aquifer. Formation hydraulic conductivity high owing to jointing and rubbly contacts between flows. Rock hydraulic conductivity low.
Quaternary and Tertiary		Rhyolitic, latitic, and andesitic rocks that occur as thick flows and blankets of welded tuff, ash, and pumice beds; includes some interbedded sediments.	Joints and fractures yield water in moderate amounts; where tightly welded, yields are poor. Commonly contains thermal water under confined conditions. An important local aquifer.
Tertiary		Basaltic rock; dense, rude columnar jointing, structurally deformed in some locations. Includes interbedded sediments.	Joints and fractures can yield water in moderate amounts. Hydraulic conductivity highly variable. An important aquifer.
Tertiary		Intrusive rocks ranging in composition from rhyolite to basalt, includes welded tuff, pyroclastics, and tuffaceous sediments.	Hydraulic conductivity generally low. May be an important aquifer locally for domestic and stock use.
Tertiary and Cretaceous		Shale, siltstone, sandstone, and fresh-water limestone, undifferentiated. Well indurated, structurally deformed in some locations.	Hydraulic conductivity generally low. Weathered zones may yield moderate quantities of water.
Tertiary and Cretaceous		Granitic rocks of the Idaho batholith.	Hydraulic conductivity generally low. Faults, fractures, and weathered zones may yield small quantities of water.
Pre-Cretaceous		Sedimentary and metamorphic rocks; well indurated and structurally deformed.	Hydraulic conductivity generally low. Faults, fractures, and weathered zones may yield small quantities of water.

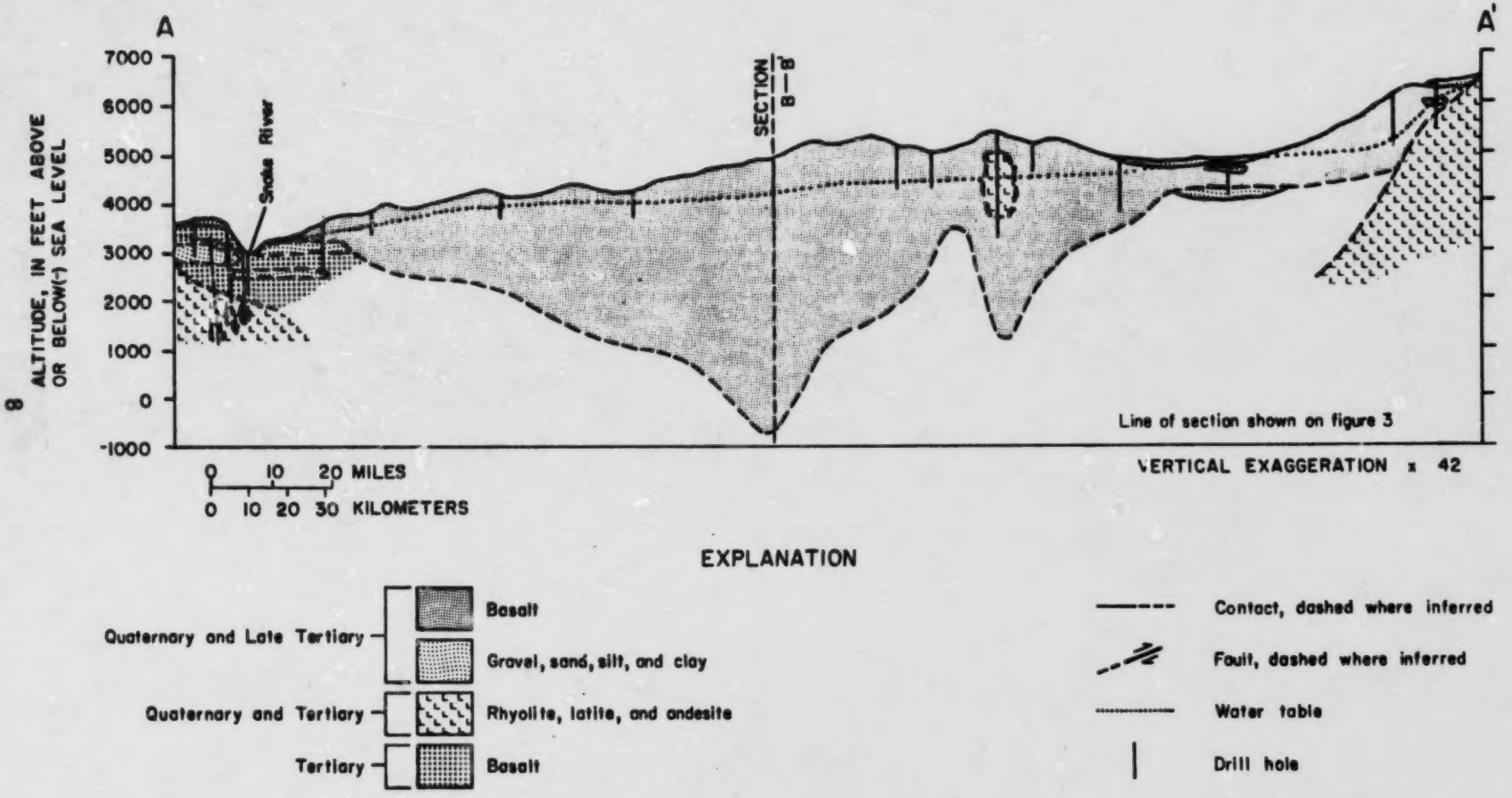
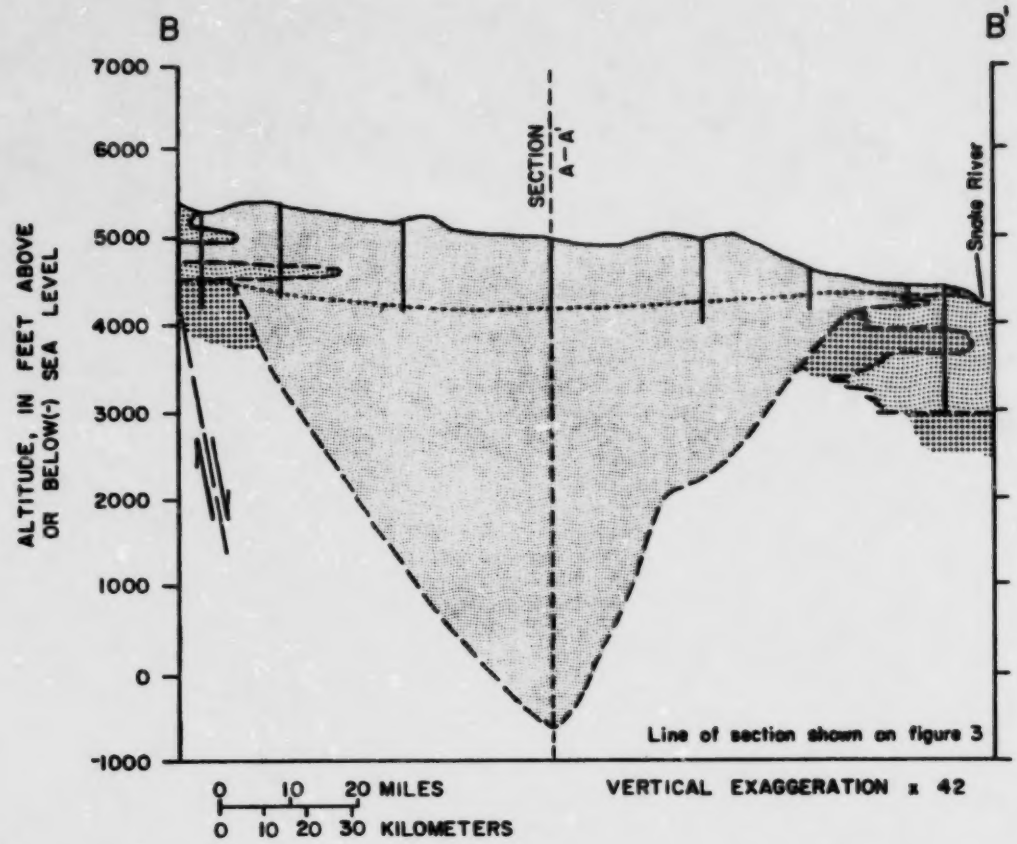


Figure 4.--Hydrogeologic section A - A'.



EXPLANATION

Quaternary and Late Tertiary — Basalt

Quaternary and Late Tertiary — Gravel, sand, silt, and clay

Tertiary — Basalt

Contact, dashed where inferred

Fault, dashed where inferred

Water table

Drill hole

Figure 5.--Hydrogeologic section B - B'.

Soil cover is minimal over younger basalt and consists primarily of windblown material. Most agriculture is in areas where soils are developed on fluvial and lacustrine deposits.

GROUND-WATER HYDROLOGY

Occurrence and movement of ground water in the regional aquifer underlying the eastern plain are dependent on the geologic framework, which determines aquifer transmissivity and storage, and recharge and discharge within that framework. Regionally, most water moves horizontally through basalt interflow zones, which are the broken and rubbly zones between lava flows. Locally, water moves vertically along joints and the interfingering edges of interflow zones.

The Quaternary basalt aquifer generally yields large quantities of water to wells. Where interflow zones include sediments and secondary minerals, transmissivity of the unit is decreased. Generally, older basalts yield less water than younger basalts as a result of secondary minerals filling vesicles, fractures, and interflow rubble zones. Aquifer thickness is largely unknown, but recent geophysical studies suggest that locally, the Quaternary basalt aquifer may be several thousand feet thick (Whitehead, 1984). It is generally believed that the upper several hundred feet are the most transmissive. Along the margins of the plain, sand and gravel several hundred feet thick transmit large volumes of water.

Recharge to the eastern Snake River Plain aquifer is from seepage of irrigation water, stream and canal leakage, tributary valley underflow, and direct precipitation. Aquifer discharge is largely spring flow to the Snake River and water pumped for irrigation. Major springs are near American Falls Reservoir and along the Snake River from Milner Dam to King Hill. Ground water generally moves from northeast to southwest, from areas of recharge to areas of discharge; movement generally is perpendicular to water-table contours (pl. 1).

A comparison of water levels for three different periods (1928-30, 1956-58, and 1980; pl. 1) indicates that regional ground-water levels and the direction of flow have been relatively stable in the central part of the eastern Snake River Plain for at least the last 50 years. However, on large tracts of land in the eastern plain (fig. 6), water levels rose an average of 60 to 70 ft (Mundorff and others, 1964, p. 162) and spring flows increased soon

10

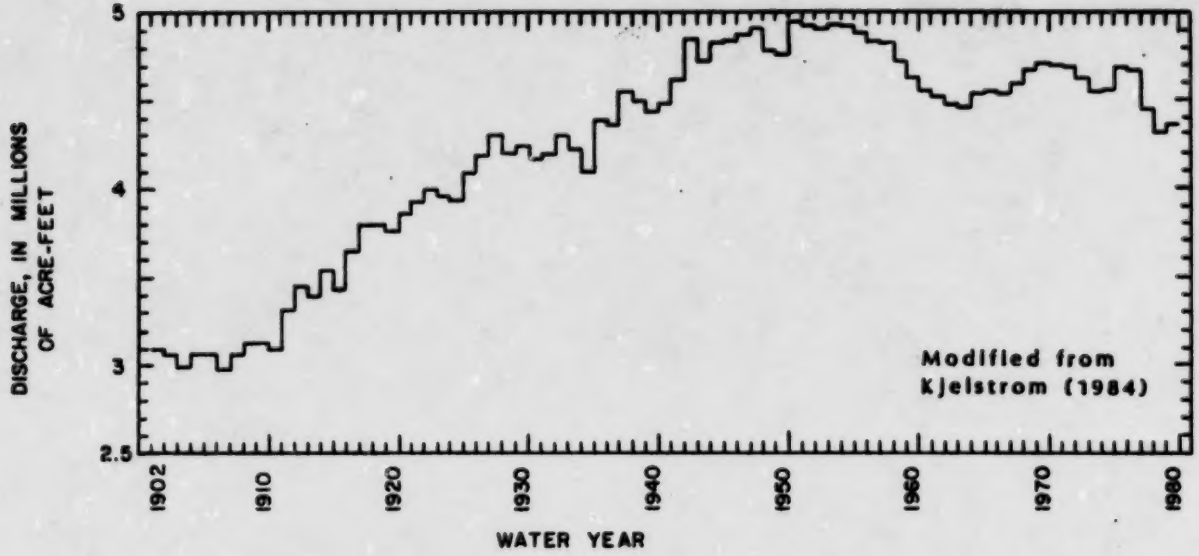


Figure 6.--Mean annual ground-water flow to the Snake River from north-side springs between Milner and King Hill.

after initiation of surface-water irrigation (about 1910). By 1928, most surface water for irrigation was appropriated; since that time, the total amount of water diverted from the Teton, Fall, Henrys Fork, Snake, and Blackfoot Rivers has been relatively stable, averaging about 8,600,000 acre-ft/yr (fig. 7). Since about 1945, amounts of ground water withdrawn for irrigation have increased. The result has been a small but, in most areas, definite decline of ground-water levels. Hydrographs on plate 1 show that water-level declines in the past 30 years have been less than 10 ft in the eastern plain.

In several areas on the eastern plain, local shallow ground-water systems have developed in the alluvium. Some of the shallow systems are perched, usually in surface-water irrigated areas where vertical flow of recharge water from irrigation is impeded by fine-grained sediments. In these areas, water levels in shallow wells may be higher than those in nearby deeper wells. Water levels in these shallow wells are representative of local ground-water conditions and not of the underlying regional flow system. For these reasons, water levels in shallow wells in several areas on the plain were not used to develop the regional water-table contours for 1980 (Lindholm and others, 1983) shown on plate 1.

The regional aquifer underlying the eastern plain is nonhomogeneous and locally anisotropic. The complex interfingering of sedimentary and volcanic rocks results in aquifer nonhomogeneity along the margins of the plain. Basalts are also nonhomogeneous because hydraulic conductivity is greatest in randomly distributed and discontinuous rubbly interflow zones; however, the lateral anisotropy caused by these zones probably occurs only locally.

Recharge

Sources of recharge to the regional aquifer underlying the eastern Snake River Plain are seepage of irrigation water, stream and canal leakage, tributary valley underflow, and direct precipitation. Steady-state calculations of recharge and discharge were based on data for the 1980 water year (October 1979 to September 1980). Surface-water diversion and return-flow data for irrigation districts are presented in watermaster reports (Idaho Department of Water Resources, 1980; and Water Districts 37, 37M, 1980) or were calculated using U.S. Geological Survey records (1980) and data from other agencies (U.S. Bureau of Reclamation, written commun., 1981). To simplify the determination of recharge from irrigation seepage, irrigation districts were grouped into areas similar to those used by Norvitch and others (1969), as shown in figure 8 and listed in appendix A.

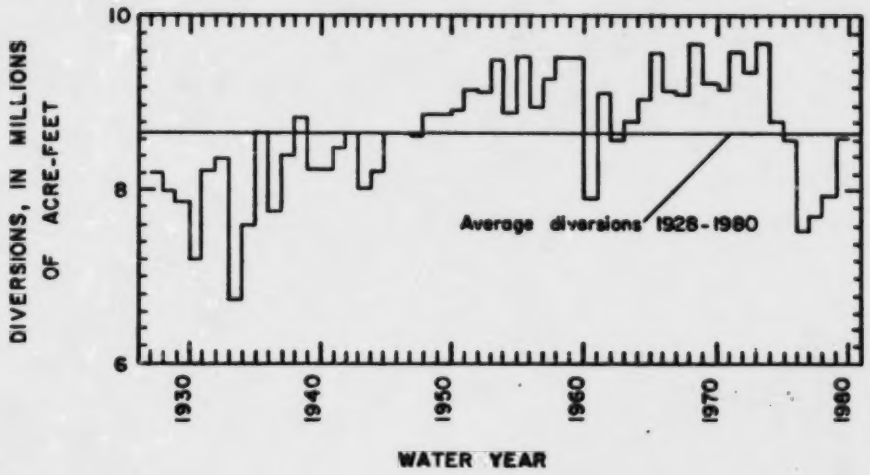


Figure 7.--Total diversions for irrigation on the eastern Snake River Plain, water years 1928-80, from the Teton, Fall, Henrys Fork, Snake, and Blackfoot Rivers.

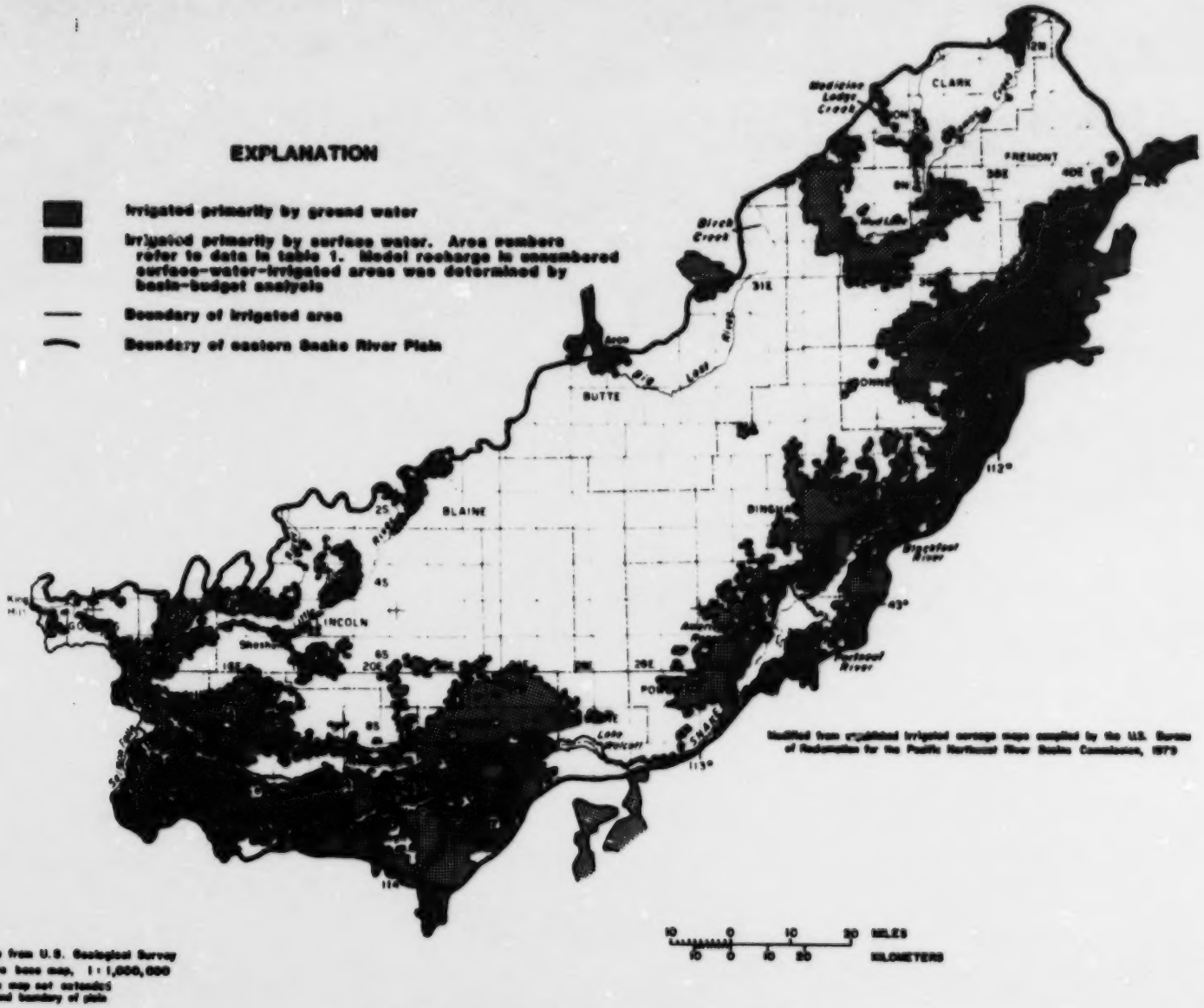

EXPLANATION
Irrigated primarily by ground water
Irrigated primarily by surface water. Area numbers refer to data in table 1. Model recharge in unnumbered surface-water-irrigated areas was determined by basin-budget analysis
Boundary of irrigated area
Boundary of eastern Snake River Plain
CLARK
FREMONT
BUTTE
BLAINE
LINCOLN
Big Lost River
Birch Creek
Medicine Lodge Creek
Teton River
Henrys Fork
Snake River
Modified from unpublished irrigated acreage maps compiled by the U.S. Bureau of Reclamation for the Pacific Northwest River Basins Commission, 1979
Base from U.S. Geological Survey
State base map, 1:1,000,000
Base map not extended beyond boundary of plain
10 0 10 20 MILES
10 0 10 20 KILOMETERS

Figure 8.---Irrigated lands in 1979.

Average recharge rates (table 1) for each surface-water irrigated area were estimated by the following equation:

$$R = \frac{D - F}{A} - ET \qquad (1)$$

where

R = recharge rate, in feet per year;
D = irrigation diversions, in acre-feet per year;
F = surface return flows, in acre-feet per year;
A = area acreage; and
ET = estimated evapotranspiration, in feet per year.

Irrigated acreages were estimated from a map of irrigated lands for 1979 (fig. 8). Evapotranspiration rates represent crop requirements adjusted for growing-season precipitation (consumptive irrigation requirement). These rates were estimated by using an empirical formula developed by Jensen and Criddle (1952) on the bases of monthly temperature, length of growing season, monthly percentage of annual daytime hours, precipitation, and crop type. Total volume of recharge to the eastern Snake River Plain aquifer from surface-water irrigation during the 1980 water year was estimated to be about 5,100,000 acre-ft.

To estimate aquifer recharge from irrigation in the Henrys Fork-Teton River basin and the Big Wood-Little Wood River basin, river losses were included with the irrigated lands recharge rate because of unmeasured diversions and return flows. Most Snake River diversions and return flows were measured or estimated in water year 1980.

Snake River losses (about 880,000 acre-ft/yr) and gains (about 7,280,000 acre-ft/yr) in 1980, calculated by Kjelstrom (1984), are listed in table 2. Average losses to the aquifer from other streams and canals (about 490,000 acre-ft/yr) over various periods of record, as determined by Kjelstrom (1984), are listed in table 3. Most canal losses were included in the determination of recharge rates for each irrigation area. However, the Milner-Gooding, Aberdeen-Springfield, and Reservation Canals lose water by seepage crossing nonirrigated lands before reaching points of delivery. These canals were treated separately in recharge calculations as distributed losses.

Average underflow from tributary valleys (about 1,230,000 acre-ft/yr) listed in table 4 was calculated by Kjelstrom (1984) using basin-yield equations. Recharge from precipitation was estimated by subdividing the eastern Snake River Plain into six areas (table 5 and fig. 9) that differ in soil type and amount of average annual precipitation. Recharge rates were modified from those used by Mundorff and

Table 1.--Estimated recharge rates for irrigated areas in 1980

Area No.	Diversions minus surface returns[1] (acre-feet per year)	Total irrigated area (acres)	Estimated evapotranspiration (feet per year)	Recharge rate (feet per year)	Area included in model (acres)	Volume of recharge to modeled area (acre-feet per year)
1	38,800	24,800	1.0	0.56	3,900	2,200
2	225,500	27,300	1.1	7.16	26,100	186,900
3	379,100	33,800	1.2	10.02	33,800	338,500
4	175,300	41,900	1.3	2.88	38,000	109,600
5	128,700	26,300	1.3	3.59	26,300	94,500
6	1,388,600	140,300	1.3	8.60	139,600	1,200,200
7	256,400	62,700	1.3	2.79	62,700	174,900
8	527,900	80,400	1.3	5.27	80,400	423,400
9	227,300	35,100	1.5	4.98	35,100	174,700
10	487,900	79,600	1.5	4.63	79,600	368,500
11	73,900	41,600	1.5	.28	38,800	10,700
12	338,500	77,200	1.6	2.78	77,200	215,000
13	48,800	18,200	1.6	1.08	18,200	19,700
14	1,022,100	162,700	1.6	4.68	161,000	753,800
15	657,300	247,200	1.6	1.06	242,200	256,500
16	60,600	15,200	1.6	2.39	15,200	36,300
17	245,800	49,000	1.6	3.42	49,000	167,400
18	44,900	13,900	1.6	1.63	9,700	15,800
19	67,100	20,500	1.6	1.67	20,500	34,300
20	62,600	17,400	1.6	2.00	17,400	34,800
21	226,100	30,100	1.6	5.91	29,900	176,800
22	106,800	5,600	1.6	17.47	5,600	97,800
23	69,200	15,300	1.6	2.92	15,300	44,700
24	36,000	11,900	1.6	1.43	11,200	16,000
25	94,700	27,400	1.6	1.86	27,400	50,900
26	129,200	20,900	1.6	4.58	20,000	91,600
Totals	7,119,100	1,326,300			1,284,100	5,095,500

[1] Calculation of diversions minus returns was discussed in Appendix A.

Table 2.--Snake River losses to and gains from ground water in water year 1980

Reach	Loss (-) or gain (+) (cubic feet per second)	Loss (-) or gain (+) (acre-feet per year)
Heise to Lorenzo	-145	-105,000
Lorenzo to Lewisville	+289	+208,900
Lewisville to Shelley	-379	-274,400
Shelley to at Blackfoot	-204	-147,800
At Blackfoot to near Blackfoot	-270	-195,600
Near Blackfoot to Neeley	+2,635	+1,907,900
Neeley to Minidoka	+453	+327,900
Minidoka to Milner	-218	-157,700
Milner to Kimberly (north side)	+30	+21,700
Milner to Kimberly (south side)	+267	+193,300
Kimberly to Buhl (north side)	+1,115	+807,200
Kimberly to Buhl (south side)	+108	+78,400
Buhl to Hagerman (north side)	+3,405	+2,465,400
Buhl to Hagerman (south side)	+275	+198,900
Hagerman to King Hill	+1,472	+1,065,700
Total loss	-1,216	-880,500
Total gain	+10,049	+7,275,300

Table 3.--Tributary stream and canal losses to aquifers based on various periods of records

Name	Loss (cubic feet per second)	Loss (acre-feet per year)	Source of data
Big Lost River	95	69,000	a
Little Lost River	17	12,500	a
Medicine Lodge Creek	69	50,200	a
Beaver Creek	46	33,100	a
Camas Creek	125	90,300	b
Clover Creek	25	18,000	a
Fish Creek	21	14,900	a
Aberdeen-Springfield Canal	263c	95,200	a
Milner-Gooding Canal	204c	96,800	a
Reservation Canal	16c	11,800	a
Totals	679	491,800	

a--Kjelstrom (1984)
b--U.S. Geological Survey (1980)
c--Losses occur only during irrigation season

Table 4.--Tributary valley underflow based on basin-yield equations

Name	Underflow (cubic feet per second)	Underflow (acre-feet per year)
Big Bend area	154	111,300
Camas Creek	208	150,700
Beaver Creek	82	59,200
Medicine Lodge Creek	12	8,400
Deep Creek	11	7,600
Warm Springs Creek	35	25,600
Birch Creek	97	70,000
Little Lost River	210	152,000
Big Lost River	418	302,600
Little Wood River	111	80,700
Silver Creek	52	38,000
Salmon Falls Creek	34	24,600
Raft River	113	82,000
Rockland Valley	70	51,000
Portneuf River	87	63,000
Totals	1,694	1,226,700

Table 5.--Estimated recharge from precipitation
[<, less than; >, greater than]

County or area	Soil cover[1]	Area (acres)	Annual precipitation (inches)	Recharge (inches)	Total volume of recharge (acre-feet per year)
Gooding, Jerome, Lincoln, Jefferson, Clark, Fremont	Thin soil cover (<40 in.), high infiltration-rate potential	1,514,500	10	1	126,200
Butte, Blaine, Minidoka	Recent lava flows, little soil cover	338,800	10	3.5	98,800
Central part of eastern Snake River Plain	Thick soil cover (>40 in.), low infiltration-rate potential	4,244,500	8-10	.3	106,100
Blaine, Power, Bingham, Bonneville	Recent lava flows, little soil cover	229,200	8	2.8	53,500
Lands adjacent to the Snake River	Thin soil cover (<40 in.), high infiltration-rate potential	747,300	10	2	124,500
Northeastern part of eastern Snake River Plain, Jefferson, Fremont, Clark	Thin soil cover (<40 in.), high infiltration-rate potential	508,100	16-20	6	254,100
Totals		7,582,400			763,200

[1] See figure 9 for distribution of generalized soil types.

Figure 9.--Distribution of generalized soil types.

others (1964) and should be considered approximate. Total annual recharge to the eastern plain from direct precipitation is about 760,000 acre-ft.

Discharge

Ground water discharges from the regional aquifer largely as seeps and springs along the Snake River from Blackfoot to Neeley and from Milner to King Hill (pl. 1). Ground-water discharge to the Snake River from Ferry Butte to American Falls Reservoir and to the Portneuf River from Pocatello to the reservoir was about 1,910,000 acre-ft in 1980 (Kjelstrom, 1984). Snake River gains in the Lorenzo to Lewisville reach in 1980 were 210,000 acre-ft and in the Neeley to Minidoka reach 330,000 acre-ft.

Springs along the Snake River from Milner to King Hill discharge from both the south and north sides of the canyon. South-side springs discharged about 470,000 acre-ft and north-side springs discharged about 4,360,000 acre-ft in 1980 (Kjelstrom, 1984).

Ground-water pumpage for irrigation continues to increase. In 1980, ground water was used to irrigate about 930,000 acres. It was assumed that the 1,640,000 acre-ft of water pumped was equal to crop evapotranspiration requirements. Any excess pumpage beyond crop requirements was assumed to return to the aquifer. The estimate is similar to the estimate of 1,760,000 acre-ft made by Bigelow and others (1984) using data on electric power consumption.

Water Budget

A 1980 water budget for the regional aquifer system underlying the eastern Snake River Plain is presented in table 6. A net loss in aquifer storage of about 130,000 acre-ft was estimated from water-level changes measured during 1980 as shown in figure 10. Storage coefficients used for the estimates are 0.05 for basalt, determined from pumping-test data (Mundorff and others, 1964), and 0.20 for sediments.

The most accurate estimates in the aquifer water budget are Snake River gains and losses--errors of estimates range from 3 to 10 percent. Recharge from surface-water irrigation is less accurate because evapotranspiration values used in calculations are empirical estimates. Evapotranspiration, which is also an important component in the estimation of ground-water pumpage, is particularly difficult to estimate for large areas where climatic conditions and crop types vary. Estimates of recharge from tributary streams and tributary valley underflow vary in accuracy because flow

Table 6.--Aquifer budget, water year 1980

Sources	Recharge (acre-feet)
Surface-water irrigation	5,095,500
Snake River loss	880,500
Tributary streams and canal loss	491,800
Tributary valley underflow	1,226,700
Precipitation	763,200
Total	8,457,700

Sources	Discharge (acre-feet)
Springs discharging to Snake River	7,275,300
Ground-water pumpage	1,641,300
Total	8,916,600
Change in storage	- 127,300

Recharge - discharge = change in storage + differences in estimates

$$\frac{\text{Differences in estimates}}{\text{Discharge}} = \frac{-331,600}{8,916,600} = -0.04$$

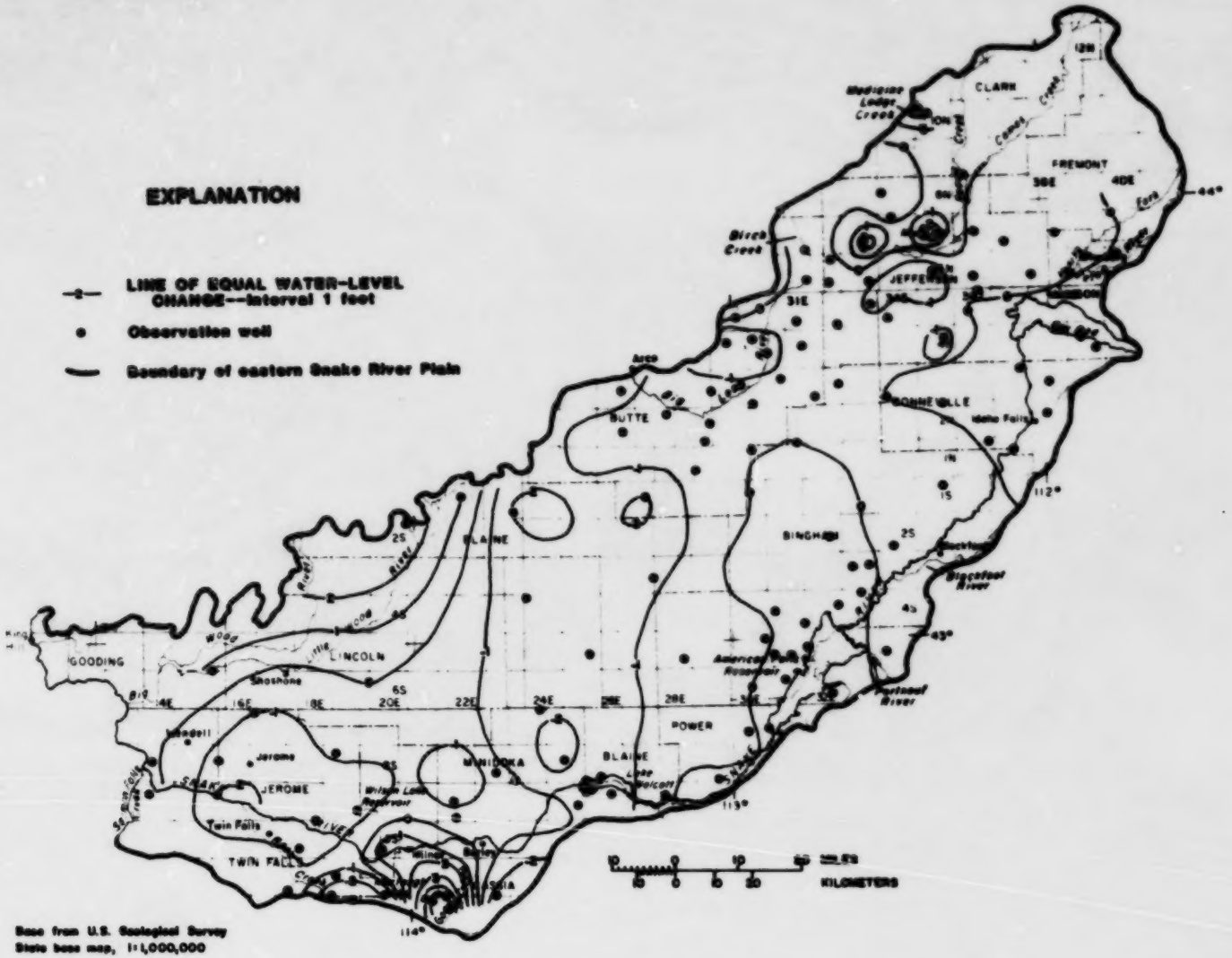


Figure 10.--Water-level changes in the regional aquifer, October 1979 to October 1980.

is measured directly in some streams and estimated from basin-yield equations in others. The value for change in storage is approximate because it is based on estimates of the aquifer storage coefficient and on measurements made in widely scattered observation wells.

The least accurate estimate in the aquifer budget is recharge from direct precipitation. Although precipitation is measured at several sites, aquifer recharge from precipitation cannot be measured directly. Possible end points of the estimate are zero or 100 percent recharge of the total direct precipitation. One hundred percent recharge from precipitation on the eastern plain would be about 6,000,000 acre-ft, or an average of 10.4 in./yr over the eastern plain. This amount of recharge puts the aquifer budget far out of balance and is therefore unreasonable. The assumption of no recharge from precipitation causes an 11.5 percent residual in the 1980 budget. Mundorff and others (1964) estimated recharge from precipitation to be about 500,000 acre-ft. Given the difference in study areas (8,400 mi^2, from Mundorff and others, 1964; versus 10,800 mi^2, from the present study), the difference between previous and present estimates of recharge from direct precipitation is reasonable.

The overall budget error of estimate is from 10 to 20 percent, owing to compensating errors in calculations of evapotranspiration, basin yields, and recharge from precipitation. Within the context of these errors, the budget residual of 4 percent (table 6) was considered acceptable.

GROUND-WATER FLOW MODEL

The flow model is based on the following partial differential equation that describes steady-state, two-dimensional ground-water flow (Cooley, 1977, 1979):

$$\frac{\partial}{\partial x}\left(T_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(T_{yy}\frac{\partial h}{\partial y}\right)+R(H-h)+W+\sum_{p=1}^{M}Q_p\delta(x-a_p)\delta(y-b_p)=0 \qquad (2)$$

where

T_{xx}, T_{yy} = transmissivity in the x and y Cartesian coordinate directions, which are to be aligned with the principal transmissivity axes, in square feet per second;

R = leakance (hydraulic conductivity divided by thickness) of streambed and spring confining bed, in feet per second per foot;

H = head in stream, spring vent, or opposite side of confining bed, in feet;

h = hydraulic head in the aquifer, in feet;

W = areally distributed recharge and discharge, in feet per second;

M = number of point-source sink terms; and

Q_p = source or sink term (well) at point (a_p, b_p), as a volume per unit surface area per unit time, in feet per second.

The terms in equation (2) are time-averaged values, where variability of values such as seasonal pumpage is averaged over a given time period. Aquifer properties are distributed by zones in which the property is held constant; however, zonal boundaries of different properties need not be the same (fig. 11).

The numerical approximation and solution of equation (2) are based on a finite-difference, mesh-centered discretization (fig. 12). The mesh spacing is held constant ($\Delta x = \Delta y$) in this report.

The regression procedure used in solving for optimum model hydraulic parameters is a minimization of the sum of squared errors of head differences between model-simulated heads and observed heads and is based on a modified Gauss-Newton method (Cooley, 1977). The sum of squares (SQ) criterion is defined as:

$$SQ = \sum_{I=1}^{N} W_I \left(h_I^{obs} - h_I^c\right)^2 \qquad (3)$$

where

N = total number of observations;

W_I = weighting factor, an expression of the reliability of the head observation, I;

h_I^{obs} = observed head; and

h_I^c = simulated head.

Regression parameters can be T_{xx}, T_{yy}, R, W, boundary flux, or constant head values. Zones may be combined to form a single regression parameter so that resultant values in each zone would be changed by the same amount during the regression procedure; that is, the ratio of the zonal values would remain the same. Prior information about regression parameters may be incorporated into the model to improve calibrated estimates. This part of the technique is described by Cooley (1982) and requires an unbiased initial estimate of the parameter as well as the coefficient of variation (standard deviation divided by expected value) of the estimate.

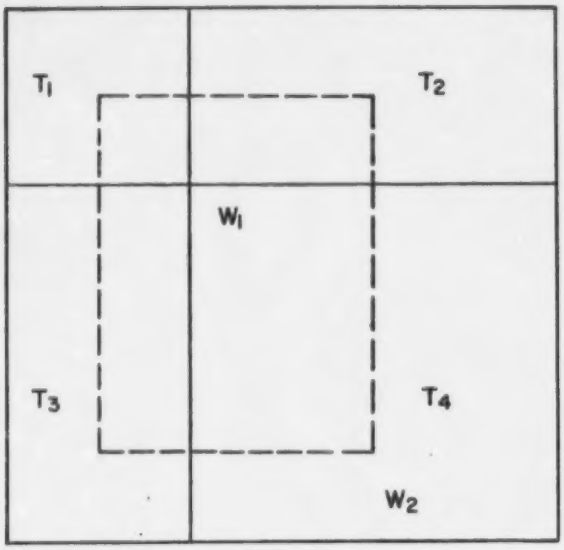


Figure 11.--Example of aquifer zonation. (T and W represent distributed aquifer parameter values; modified from Cooley, 1977)

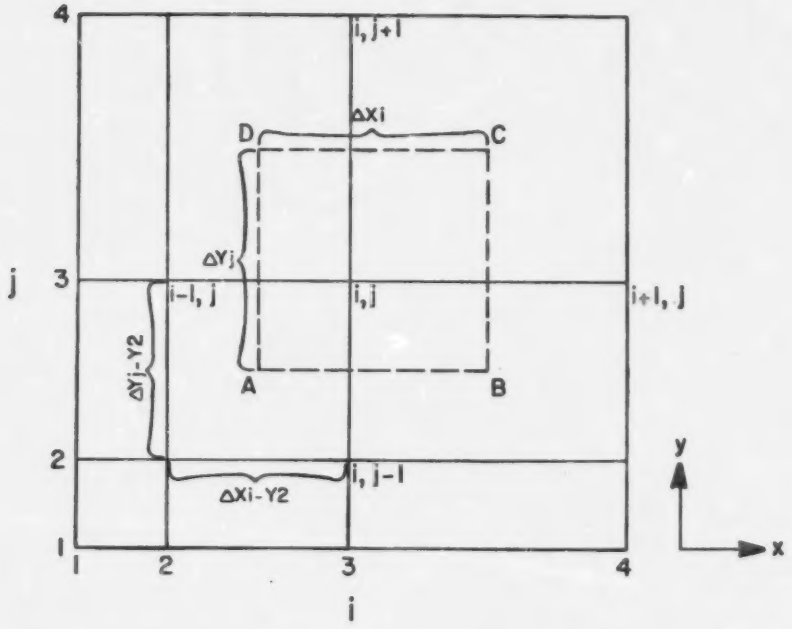


Figure 12.--Finite-difference, mesh-centered grid notation. (A, B, C, D, represent blocks of distributed aquifer parameter values around node i, j)

A computer program by R. L. Cooley (U.S. Geological Survey, written commun., 1981) that implements the least-squares procedure is described in appendix B; the program listing is appendix C. The program was modified by addition of mass-balance calculations and the use of interpolated simulated heads where measured heads were not at nodes. This was necessary because many blocks had several head observations and node points were not located at points of head observations. The following equation is used to calculate interpolated heads:

$$h^c = ax + by + cxy + d \qquad (4)$$

where

h^c = interpolated head;

h_1, h_2, h_3, h_4 = heads at block corners (fig. 13),

$a = h_2 - h_1$,

$b = h_3 - h_1$,

$c = h_4 + h_1 - h_2 - h_3$,

$d = h_1$;

x = fractional distance from lower left corner of unit block along the x-axis (fig. 13); and

y = fractional distance from lower left corner of unit block along the y-axis (fig. 13).

This interpolation equation also was used to interpolate the arrays used in the least-squares estimation of parameters. Changes made using the interpolation equation are noted in comment statements throughout the program listing (appendix C).

APPLICATION OF GROUND-WATER FLOW MODEL TO THE EASTERN SNAKE RIVER PLAIN REGIONAL AQUIFER

The approach taken in this study of the regional aquifer was to develop recharge estimates as a starting point for calibrating estimates of transmissivity and other aquifer parameters. A similar approach was used by previous investigators (Mundorff and others, 1964; Norvitch and others, 1969; and Newton, 1978) because fluxes in the regional system, particularly spring discharges, are more accurately measured than aquifer transmissivities and leakances. Reported transmissivities calculated from aquifer tests are typically minimum values and represent only local conditions around a partially penetrating well.

Recharge rates based on 1980 water year data and distributed to each block were calculated using the following equation:

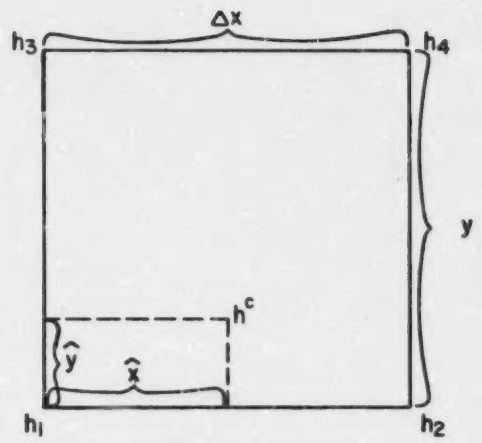


Figure 13.--Notation for head interpolation ($x = \hat{x}/\Delta x$, $y = \hat{y}/\Delta y$).

$$RB(i,j) = \frac{1}{AB(i,j)}\left[\left(\sum_{K=1}^{N} SW_K \cdot A_K(i,j)\right) + U(i,j) + SC(i,j) + P(i,j) + \Delta S(i,j) + GW(i,j)\right] \quad (5)$$

where

RB(i,j) = recharge rate for block (i,j), in feet per second;
AB(i,j) = area of block (i,j), in square feet;
N(i,j) = number of irrigation areas in block (i,j);
SW_K = recharge rate for irrigation area (K) (table 1), in feet per year;
$A_K(i,j)$ = total acreage for irrigation area (K) in block (i,j);
U(i,j) = tributary valley underflow in block (i,j) (table 4), in cubic feet per second;
SC(i,j) = stream and canal losses in block (i,j) (tables 2 and 3), in cubic feet per second;
P(i,j) = recharge from precipitation in block (i,j) (table 5), in cubic feet per second;
ΔS(i,j) = change in storage per unit time in block (i,j), in cubic feet per second; and
GW(i,j) = ground-water pumpage in block (i,j), in cubic feet per second.

Model Grid and Boundary Conditions

Model grid and boundary conditions are illustrated on plate 2. The grid was oriented in a northeast-southwest direction to minimize the number of inactive blocks, to make the x-direction parallel to the major direction of ground-water flow, and to make the y-direction parallel to rift zones crossing the plain (fig. 3). Boundary conditions included constant flux and head-dependent river and spring blocks. Constant flux for each block was calculated using equation (5). Boundary fluxes shown on plate 2 are listed in table 4. Where the amount of underflow was unknown, boundary flux was calculated as a separate regression parameter. Aquifer recharge calculated by equation (5) varied from block to block across the aquifer. Largest values were in areas of surface-water irrigation; smallest values were in areas where ground-water pumpage exceeded recharge, which resulted in a negative flux.

Aquifer discharge to the Snake River (largely as spring flow) was simulated as leakage across a confining bed. River or spring heads were held constant but head losses were allowed between the aquifer and these constant heads. The control on head loss--leakance--is the hydraulic conductivity of the confining bed divided by the bed thickness.

This type of boundary condition allowed good control of discharge to the river and springs. Each of the gaining reaches of the Snake River shown in table 2, except the Lorenzo to Lewisville reach, was modeled using head-dependent discharge blocks (pl. 2). The Lorenzo to Lewisville reach was treated as a constant flux. In that reach, ground-water discharge during the irrigation season is primarily from the shallow alluvial system. The shallow alluvial system also recharges the deeper regional basalt aquifer. Head relations between the shallow system and the regional system do not indicate upward movement of water during the irrigation season when that reach of the river is gaining. Therefore, discharge to the river from the shallow alluvial system reduces the amount of recharge to the underlying regional system in this area.

Model Assumptions

Several major assumptions were made in the use of this model. Ground-water flow in the aquifer was assumed to be laminar (Darcian flow). Although this may not be true locally, particularly near spring vents, head gradients across most of the eastern plain are relatively low (averaging about 17 ft/mi); therefore, ground-water flow is likely to be laminar. Isotropic permeability was initially assumed because rubbly interflow zones, the most transmissive part of basalt flows, appear to be random and discontinuous. However, large-scale fractures in the rift zones crossing the plain (fig. 3) might cause anisotropic conditions over a broad area. Nonhomogeneity of aquifer properties (transmissivity and leakance) was accommodated by zoning the aquifer into areas where a limited range of parameter values was expected. Model-calculated values then represented an average within the zone.

Ground-water flow was assumed to be generally horizontal (two dimensional). This assumption is valid for the central part of the plain, where there is little recharge or discharge to cause vertical flow; however, along the margins of the plain, vertical flow components do exist. Because much of the vertical flow occurs in sediments overlying the regional aquifer, only heads from wells completed in the regional aquifer were used in simulations. Therefore, calculated transmissivity values are representative of only the underlying regional aquifer.

In some parts of the eastern Snake River Plain, head changes significantly with depth. In the Mud Lake area, a complex interlayering of basalt and sediments causes variations in head within the regional ground-water system. Therefore, the assumption of two-dimensional flow is only an approximation of the flow system. Changing heads with

depth also were observed in wells in Gooding and Jerome Counties near the major discharge area for the regional ground-water system. However, throughout most of the plain, regional ground-water flow is approximately horizontal.

Ground-water flow in the regional aquifer was assumed to be near steady state during the 1980 water year. Water levels have been stable during the past 30 years; rises and declines have been less than 10 ft across the plain. During water year 1980, storage changes in the regional aquifer were small, as indicated by the small net change in storage (table 6) and small head changes (fig. 10). Spring discharge to the Snake River from near Blackfoot to Neeley has been stable, fluctuating between about 2,500 and 2,600 ft^3/s for the past 60 years. North-side spring discharge to the Snake River from Milner to King Hill has been stable, fluctuating between about 6,000 and 6,500 ft^3/s for the past 20 years. The stability of water levels and discharge is due to the relative constant recharge from surface-water diversions, as shown in figure 7. Diversions in 1980 were about the same as the average for the period 1928-80. Effects of transient flow in the shallow system overlying the regional aquifer were assumed to be negligible in the long-term, steady-state calculations of recharge based on 1980 water year data. It also was assumed that recharge moves from the shallow zones downward into the regional system within irrigated area boundaries (fig. 8).

Model Calibration

Water levels measured in 824 wells in the spring of 1980 were used in the calibration procedure. Water levels were assigned a weighting factor (W_i) of 1.0, as there was little basis for differentiating among the measurements. Initial zonation of transmissivity was made on the basis of rock type (sediment, basalt) and water-level gradients.

Transmissivities and leakances initially were considered to be regression parameters in the calibration process. In early simulations, unrestrained leakance regression parameters were unstable, resulting in negative parameter values. When leakance and recharge were held constant and transmissivity was calibrated as a regression parameter, the model became stable. Leakance values were adjusted manually from simulation to simulation until model-calculated spring flow aproximated measured spring flow. Some spring vent altitudes were varied within reasonable ranges to obtain a better comparison between measured and calculated water levels.

Calibration proceeded in a stepwise manner--results of the previous simulation were used as initial values for the

next simulation. If an individual zone caused instability and poor simulation results, zones were combined to form a single regression parameter. Transmissivities were adjusted by modifying zone boundaries and allowing the program to compute an optimum fit to water levels. If, within a zone, major differences were noted between model-calculated and measured water levels, the zone was split or rearranged for further model simulations. Zones were added along margins of the plain where transmissivity is reduced because the aquifer is thin and sediments are interlayered with basalt (figs. 3, 4, and 5).

Boundary flux was added as a regression parameter in some areas where the flux was unknown to better simulate the direction of flow. This additional parameter resulted in better comparison of model-calculated discharge with measured aquifer discharge. In the final stages of calibration, transmissivity, leakance, recharge, and boundary flux were made regression parameters. Transmissivity and boundary flux were unrestrained, whereas recharge and leakance were used as prior information parameters with various values of coefficients of variation.

A measure of overall goodness of fit of model simulations is the error variance (s^2) (Cooley, 1977):

$$s^2 = \frac{\sum_{i=1}^{J} W_i (h_i^{obs} - h_i^c)^2}{J - K} \qquad (6)$$

where

W_i = weighting factor;

$h_i^{obs} - h_i^c$ = head residual, the difference between observed and calculated head;

J = number of head observations; and

K = number of regression parameters.

The standard error of estimate for head, defined as the square root of the error variance, was plotted against model run number (fig. 14). The plot indicates a rapid initial decrease in standard error as more regression parameters were used. However, as more regression parameters were added, there were more occurrences of nonconvergence and invalid parameter values (negative transmissivities). Figure 14 also indicates a diminishing return in model improvement (decreased standard error) as model runs and changes progressed.

Along with standard error of estimate for head, model-calculated spring discharges were an important criterion of

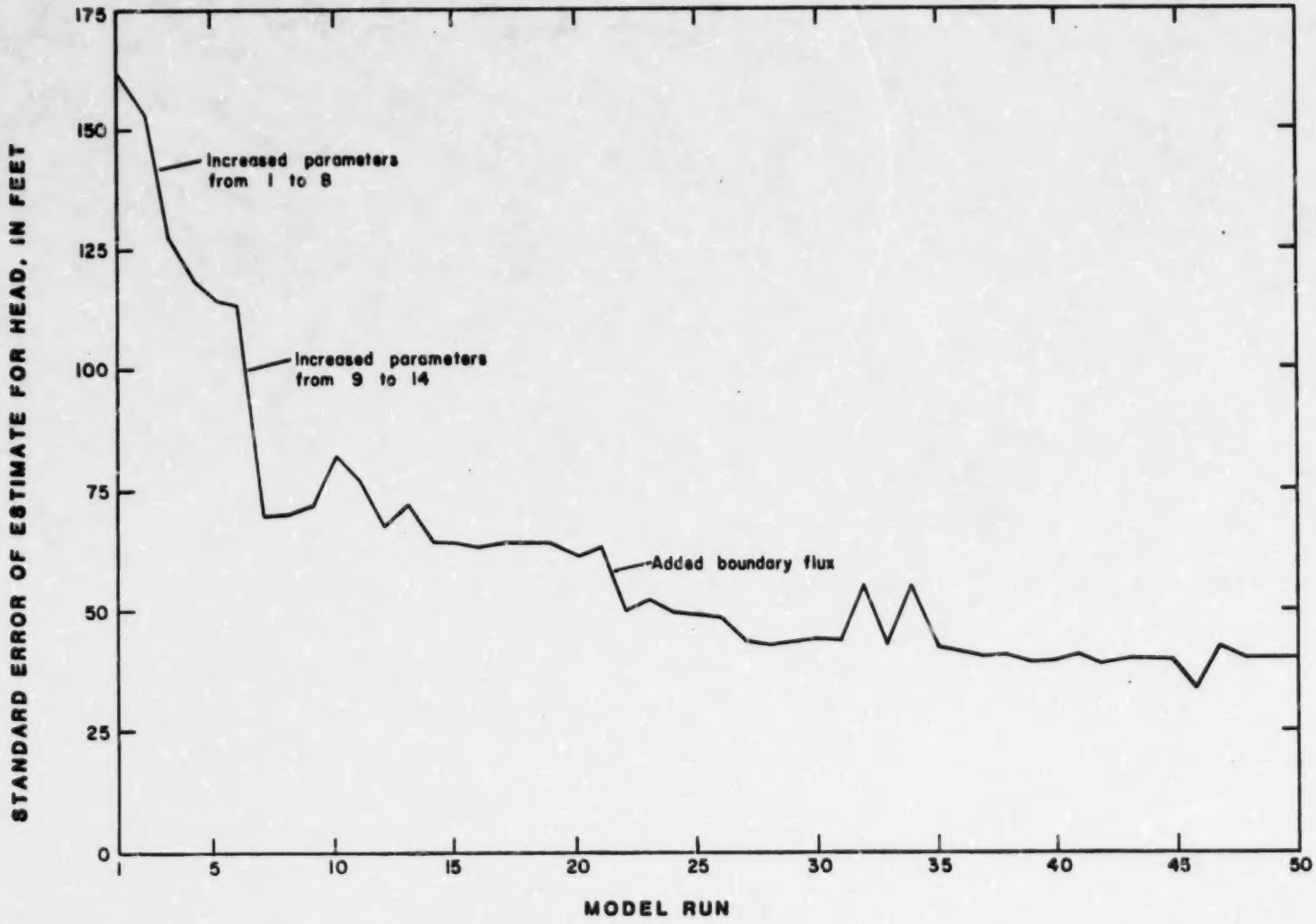


Figure 14.--Model-run standard errors of estimates.

model fit. Calculated transmissivities were strongly affected by the distribution of flux within the model. Many of the final simulations involved adjustments of leakance to match calculated spring discharges to measured spring discharges.

Contours based on model-calculated heads (run 40) were compared with contours based on spring 1980 water-level measurements (pl. 3). This comparison indicates that the flow model reasonably simulates both the major direction of ground-water flow and the magnitude of ground-water levels. The ratio of the standard error of estimate for heads (run 40) to total head loss in the system is $s/\Delta h = 40.4/3,619 = 0.011$, which indicates that the errors are only a small part of the overall model response.

To statistically analyze results of the regression model, modeled head residuals were assumed to be random variables with zero mean, to have a constant variance, and to be uncorrelated (Cooley, 1979). It is also assumed that the set of head residuals has a multivariate normal distribution. These assumptions allow the use of statistical tests and measures involving the F and t distributions.

Modeled head residuals generally have a random distribution throughout the central part of the modeled area. However, in several places, particularly along the margins of the plain, large absolute values of head residuals are apparent. They appear where model assumptions were violated or the model zones were inadequate to describe local variations in aquifer parameters. The steady-state flow assumption was violated in areas southwest of Burley (zones 19 and 20, pl. 2). Owing to continuing declines in water levels, the Idaho Department of Water Resources has declared a moratorium on further development in these areas. Although the water-level-change map (fig. 10) indicates some recovery during water year 1980, these areas probably are not yet in steady-state conditions. Large head residuals also appear in the Mud Lake area (zone 12) owing to the large head changes with depth in this area.

Transmissivity changes in some areas were not simulated adequately owing to the block size used in this study. An example is the river reach from Kimberly to Buhl (zones 2 and 3). In that reach, highly permeable rocks that fill ancestral Snake River canyons cause large transmissivity changes over short distances and changes in flow direction in the immediate vicinity of spring vents. Large changes in aquifer properties over short distances also occur in the Shoshone-Gooding (zones 2 and 18), Mud Lake (zone 12), and

Camas Creek (zone 16) headwater areas. Changes in aquifer properties cause poor model fit and large absolute values of residuals in these areas.

Comparison of Simulations

Regression parameters for seven different model simulations are presented in table 7. These simulations were used to test assumptions and various configurations of the model. There is no best simulation presented; instead, results are compared for indications of model improvement. Statistical results for these simulations are presented in table 8, measured and calculated spring discharge are compared in table 9, calculated transmissivities are shown in table 10, and mass-balance calculations are presented in table 11.

Although discussion of individual simulations follows, the similarity of results should be noted. In particular, the measured and calculated spring discharges show good agreement (table 9), which indicates that the mass-flux distribution was good in this set of simulations. The small variation of results obtained when zonation was held constant as compared with the larger variation for earlier simulations where zonation was varied implies that the underlying structure of the model zonation is the single most important influence on modeling results. The zones used in this set of simulations were developed using geologic and hydrologic information and represent a simplification of continuously varying geologic and hydrologic parameters. Within the constraints of the number of head observations, the stability of the model, and the accuracy of mass flux estimates, results from the zonation as presented here appear to be good representations of average aquifer conditions.

To investigate the significance of reduction in error variance from one model simulation to another, the approximate probability of occurrence of the ratio of the two error variances using the F distribution was computed. This approximation resulted from the F distribution, which assumes statistical independence of the two error variances used to form the ratio, whereas the two error variances used here are probably positively correlated (R. L. Cooley, U.S. Geological Survey, written commun., 1984). This correlation would cause the ratio to be consistently smaller than it would be if the variances were independent. Thus, the actual probability of occurrence is generally less than the probability computed using the F distribution. Further assumptions that limit exact interpretation of the F statistic are the assumptions of model linearity (the regression model is assumed to be linear in the parameters) and normal distribution of head residuals.

Table 7.--Regression parameters for simulations 40, 42, 46-50

[Aquifer property and zone of calibration (pl. 2), where T = transmissivity, SL = leakance, QRE = recharge, and BF = boundary flux; the associated numbers are zone numbers]

Regression parameter No.	Run 40	Run 42	Run 46	Run 47	Runs 48-50
1	BF,1,19	BF,1,19	T,2,3	BF,1,19	BF,1,4,7,11, 13,14,16-20
2	T,1,19	T,x-direction	T,4	T,1,19	T,1,19
3	T,2,3	T,y-direction	T,5,10	T,2,3	T,2,3
4	T,4		T,6	T,4	T,4
5	T,5,10		T,7,8	T,5,10	T,5,10
6	T,6		T,9	T,6	T,6
7	T,7,8		T,11,17	T,7,8	T,7,8
8	T,9		T,12	T,9	T,9
9	T,11,17		T,13	T,11,17	T,11,17
10	T,12		T,14,15	T,12	T,12
11	T,13		T,16	T,13	T,13
12	T,14,15		T,18	T,14,15	T,14,15
13	T,16		T,20	T,16	T,16
14	T,18			T,18	T,18
15	T,20			T,20	T,20
16					SL,7,17
17					SL,1,2,3, 18,20
18					QRE,2,3,4, 18,20
19					QRE,11,13, 14,17
20					QRE,1,5-10, 12,15,16,19

Table 8.--Statistical results for simulations 40, 42, 46-50

Statistic, or number of observations	Simulations						
	40	42	46	47	48	49	50
Error variance, in feet squared	1.63×10^3	1.54×10^3	1.16×10^3	1.82×10^3	1.63×10^3	1.62×10^3	1.62×10^3
Standard error of estimate for heads, in feet	40.4	39.2	34.1	42.70	40.32	40.29	40.25
Sum of squared errors	1.32×10^6	1.26×10^6	8.52×10^5	7.51×10^5	1.32×10^6	1.31×10^6	1.31×10^6
Correlation between observed and calculated heads	0.9964	0.9966	0.9976	0.9961	0.9964	0.9964	0.9965
Mean head residual, in feet	-1.19	-1.61	-1.17	-2.84	-0.81	-0.52	-0.42
Mean of absolute value of head residuals, in feet	28.87	28.18	24.97	28.60	28.79	28.74	28.68
Number of observations	824	824	[1]746	[1]427	824	824	824

[1] Some data were removed; see discussions presented in text.

Table 9.--Comparison of model-calculated and measured spring discharge

Snake River reach/location	Measured discharge (cubic feet per second)	Model-calculated discharge (cubic feet per second)							Model leakance, in foot per second per foot (standard error x 10^{-9})			
		Run 40	Run 42	Run 46	Run 47	Run 48	Run 49	Run 50	Runs 40,42,46,47	Run 48	Run 49	Run 50
Near Blackfoot to Neeley	2,635	2,550	2,686	2,497	2,338	2,609	2,685	2,800	27.6	27.8 (1.4)	28.7 (2.6)	31.4 (5.0)
Neeley to Minidoka	453	419	395	409	367	425	436	452	5.0	5.0 (0.2)	5.2 (0.5)	5.7 (0.9)
Milner to Kimberly	297	318	242	160	279	306	292	271	6.0	5.8 (0.2)	5.5 (0.4)	5.1 (0.6)
Kimberly to Buhl	1,223	1,232	1,170	1,055	1,219	1,202	1,160	1,080	6.0	5.8 (0.2)	5.5 (0.4)	5.1 (0.6)
Buhl to Hagerman	3,680	4,081	4,049	3,773	4,326	4,122	4,054	3,750	60.0	57.8 (2.4)	55.2 (4.4)	51.0 (6.6)
Hagerman to King Hill	1,472	1,210	1,290	1,166	1,269	1,223	1,207	1,130	2.2	2.1 (0.1)	2.0 (0.1)	1.9 (0.2)
Totals	9,760	9,810	9,832	9,060	9,798	9,887	9,834	9,483				

Table 10.--Transmissivity values for simulations 40, 42, 46-50
[T, transmissivity; x, x-direction; y, y-direction; ---, no data available; values in feet squared per second]

Zone No.	Run 40		Run 42				Run 46		Run 47		Run 48		Run 49		Run 50	
	T	Standard error	Tx	Standard error	Ty	Standard error	T	Standard error	T	Standard error	T	Standard error	T	Standard error	T	Standard error
1	0.159	0.0064	0.151	0.0017	0.188	0.0055	---	---	0.152	0.00953	0.163	0.0105	0.163	0.0168	0.156	0.0272
2	11.7	.577	11.1	.124	13.8	.408	11.0	0.466	12.7	.840	11.9	.765	11.7	1.05	10.7	1.56
3	.064	.0031	.061	.00068	.075	.0022	.06	.0025	.0693	.00458	.0648	.00417	.0638	.00574	.0584	.00852
4	9.11	.676	8.64	.097	10.7	.317	12.7	.96	10.2	1.15	8.95	.785	8.48	1.02	7.27	1.39
5	.516	.059	.489	.0055	.608	.018	.481	.043	.520	.154	.522	.0658	.524	.0788	.508	.105
6	27.2	7.60	25.8	.289	32.1	.948	27.2	5.32	27.2	9.64	27.7	8.00	27.0	8.30	24.2	8.59
7	6.19	.930	5.87	.066	7.30	.216	4.97	.802	6.35	1.30	6.06	.995	5.66	1.12	4.72	1.29
8	12.4	1.86	11.7	.132	14.6	.431	9.95	1.60	12.7	2.60	12.1	1.99	11.3	2.24	9.45	2.59
9	.833	.316	.790	.0089	.982	.029	1.40	.376	1.01	.425	.829	.317	.796	.310	.693	.291
10	1.03	.119	.978	.011	1.22	.036	.963	.086	1.04	.308	1.04	.132	1.05	.158	1.02	.210
11	43.9	2.42	41.6	.467	51.8	1.53	41.0	2.06	40.7	3.10	44.3	3.08	43.7	4.07	41.0	5.91
12	.672	.092	.638	.0071	.793	.023	.758	.084	.964	.235	.676	.0952	.669	.101	.632	.117
13	7.92	.822	7.50	.084	9.33	.276	8.17	.719	6.37	1.06	7.94	.886	7.79	1.01	7.34	1.28
14	9.15	.974	8.67	.097	10.8	.319	9.39	.85	9.28	1.90	9.21	1.03	9.10	1.13	8.60	1.37
15	13.2	1.41	12.5	.141	15.6	.460	13.6	1.23	13.4	2.75	13.3	1.48	13.2	1.63	12.4	1.98
16	.147	.0036	.139	.0016	.173	.0051	.146	.003	7.31	26.1	.148	.00799	.148	.0139	.141	.0234
17	43.9	2.42	41.6	.467	51.8	1.53	41.0	2.06	40.7	3.10	44.3	3.08	43.7	4.07	41.0	5.91
18	.170	.009	.162	.0018	.201	.0059	.177	.0083	.146	.0101	.175	.0121	.180	.0168	.184	.027
19	.050	.002	.047	.00053	.059	.0017	---	---	.0475	.00298	.0508	.00329	.0509	.00523	.0487	.00849
20	12.8	1.23	12.2	.136	15.1	.447	9.02	1.05	12.2	1.78	12.8	1.33	12.4	1.51	11.4	1.93

Table 11.--Mass-balance calculations[1] for simulations 40, 42, 46-50
[---, no data available; values in cubic feet per second]

Run No.	Recharge		Spring discharge		Additional boundary flux		
	Value[2]	Standard error	Value	Standard error	Constant flux	Value	Standard error
40	9,294	---	9,810	---	364	152	7.9
42	9,294	---	9,832	---	364	174	6.6
46	8,713	---	9,060	---	347	---	---
47	9,294	---	9,798	---	364	140	10.4
48	9,359	440	9,887	430	---	528	37.5
49	9,306	840	9,834	774	---	528	55.6
50	8,978	1,490	9,483	1,280	---	505	87.7

[1]Mass balance equation: recharge + boundary flux - spring discharge = 0

[2]Example of recharge calculation:

	Acre-feet per year	
Surface-water irrigation	5,095,500	table 6
Snake River loss	880,500	
Tributary streams and canal loss	491,800	
Tributary-valley underflow	1,226,700	
Precipitation	763,200	
Ground-water pumpage	-1,641,300	
Snake River gain (Lorenzo to Lewisville)	-208,900	table 2
Change in storage	127,300	table 6
Total	6,734,800, or 9,302 cubic feet per second	

In run 42, all of the x-direction transmissivities were calibrated as a combined regression parameter independent of the combined y-direction transmissivities to test for anisotropy in the regional aquifer. Thus, all the ratios between the x-direction transmissivities remain the same, as do the y-direction transmissivities; only the ratio between the x and y transmissivities changes. Transmissivity values determined by run 40 were used as initial values for run 42. The error variance for run 42 was reduced from that in run 40 (table 8); the variance ratio is computed to check the significance of the reduction:

$$\frac{\text{error variance (run 40 1,630)}}{\text{error variance (run 42 1,540)}} = 1.06$$

and Prob [F (J-K,J-M) > 1.06] $\simeq 0.21$

where

F (J-K,J-M) = the value of the F distribution with J-K and J-M degrees of freedom,
J = number of head observations (824),
K = number of regression parameters in run 40 (15), and
M = number of regression parameters in run 42 (3).

Because the computed probability on the basis of the F distribution is 0.21, the actual probability of occurrence of the value 1.06 is probably less than 0.21. Hence, the reduction of variance may be significant at about the 0.05 level, but further evidence is needed.

Run 42 results indicate an x-direction transmissivity to y-direction transmissivity ratio (T_x/T_y) of about 0.80 (table 10), which suggests that the medium is not highly anisotropic. However, the standard errors for T_x and T_y are small enough to suggest that T_x and T_y might be significantly different. From table 10, it can be seen that $T_x + 3 \cdot$ (standard error of T_x) $< T_y - 3 \cdot$ (standard error of T_y). Hence, with approximately 99 percent confidence, T_x and T_y are different (see Graybill, 1976, p. 360), even though they are not greatly different numerically. This result is supported by geologic evidence shown in figure 3. Fractures and faults in rift zones, parallel to the y-direction, may increase hydraulic conductivity along the trace of the fracture or fault, thereby increasing the y-direction transmissivity. However, the results of the statistical tests can only be interpreted as preliminary indications of

anisotropy in the regional system, as there was little reduction in error variance, and calculated values of x-direction and y-direction transmissivities are similar.

In run 46, zones 1 and 19 and parts of zones 4 and 20, corresponding to the area south of the Snake River from Twin Falls to Burley, were removed from the system (table 7). Model run 40 had several large absolute values of head residuals within zones 1 and 19 that resulted from violation of model assumptions (two-dimensional and steady-state flow). By removing those zones from the model, the error variance was reduced greatly compared with run 40 (table 8):

$$\frac{1{,}630 \text{ (run 40)}}{1{,}160 \text{ (run 46)}} = 1.41; \text{ Prob } [F(809,811) > 1.41] \simeq 2 \times 10^{-9}.$$

Using a range of ± 2 standard errors as an indication of roughly 95 percent confidence (similar to the comparison of T_x and T_y previously), values of transmissivity in zones 4 and 20 in run 46 are significantly different from those in run 40. Except for zone 4, all the standard errors for transmissivity are lower in run 46. This simulation indicates the importance of removing zones that violate model assumptions.

Run 47 is a test of the model using 427 head observations measured in August 1980. Head differences occur in many wells between spring and late summer owing to seasonal application of irrigation water and pumping (pl. 1). Water levels in pumping areas are typically lowest in August, whereas in areas of applied surface water, they are typically highest in late summer and early fall (pl. 1). Seasonal variations in many wells in irrigated areas are greater than the long-term trend for the period of record (pl. 1). The error variance for run 47 was slightly greater than for run 40 (table 8):

$$\frac{1{,}820 \text{ (run 47)}}{1{,}630 \text{ (run 40)}} = 1.12; \text{ Prob } [F(412,809) > 1.12] \simeq 0.085.$$

However, because two separate data sets were used for run 40 and run 47, the two variances used to compute the ratio may be nearly independent so that the ratio may not be biased. Hence, for a level of significance of 0.05, the variance for run 47 may not be significantly different from the variance computed for run 40. Furthermore, transmissivity values determined in runs 40 and 47 (table 10) are within ± 2 standard error range of each other. Comparison of results based on run 47 with those of run 40 indicates the usefulness of the steady-state approach in estimating aquifer

properties and the stability of model results using a different set of head observations.

In runs 48, 49, and 50, all model input, including transmissivity, leakance, recharge, and boundary flux, were used as regression parameters (table 7). Transmissivity and boundary flux were allowed to vary unrestrained, whereas recharge and leakance parameters were restrained by available information. Recharge zones were grouped into major areas of agricultural lands (fig. 8) and leakance into the two major spring areas, American Falls and Milner to King Hill. The values used for leakance and recharge in runs 48, 49, and 50 were the initial values for run 40; the coefficients of variation for both leakance and recharge were set at 0.05, 0.10, and 0.20 for runs 48, 49, and 50.

The error variance and most other statistics given in table 8 for runs 48, 49, and 50 are essentially the same as for run 40. All parameter values, transmissivity (table 10), leakance (table 9), recharge (table 11), and boundary flux (table 11) are within the ± 2 standard error range of values in run 40. Standard errors for all parameters increased from run 48 to run 50 owing to the increased uncertainty in the parameter values. These simulations indicate the stability of the model to increasing uncertainty in model recharge and leakance. Because of uncertainty in recharge and leakance values, the standard errors for all parameters are more realistic in simulations 48-50 than in run 40. Although the level of uncertainty is difficult to estimate, it is not likely to exceed 0.20. If uncertainty is 0.30, for example, calculated spring discharges are not within an acceptable range, which is about 10 percent of measured spring discharges. Therefore, a reasonable range of parameters, within the model zones used in this study, is ± 2 times the standard errors given in run 50 results.

The scaled sensitivity (SW) for regression parameter m is defined as:

$$SW = \frac{\partial h_l}{\partial a_m} \cdot a_m \qquad (7)$$

where

h_l = head at location l, and

a_m = regression parameter value.

Average scaled sensitivities for run 49 for each regression parameter in each model zone are presented in table 12. Absolute values of scaled sensitivity indicate the contribution of the regression parameter to model response (for example, calculated head). Large absolute values of scaled

Table 12.--Scaled sensitivities for simulation 49
[T, transmissivity; SL, leakance, QRE, recharge; and BF, boundary flux]

Regression parameter No.	Aquifer property and zone of calibration (pl. 2)	Average sensitivity within each aquifer zone (pl. 2) 1	2	3	4	5	6	7	8	9	10
1	BF,1,4,7,11,13,14,16-20	54.31	5.707	2.599	10.01	10.30	8.478	6.108	6.377	6.383	7.103
2	T,1,19	[1]-290.5	.5782	-2.466	-.1447	-.09394	-.1178	-.09421	-.1046	-.06723	-.02794
3	T,2,3	-55.69	[1]-105.9	-2.365	[1]-151.1	[1]-119.0	[1]-110.0	[1]-52.57	[1]-64.75	[1]-62.75	-24.97
4	T,4	15.84	45.64	12.78	-14.90	-84.69	[1]-79.36	-36.66	-45.22	-45.31	-17.98
5	T,5,10	.2226	.4121	.1264	1.327	[1]-112.1	2.153	.6496	.8604	2.189	-83.50
6	T,6	4.522	9.586	2.858	25.70	15.50	4.744	-1.823	-5.538	-14.80	-5.918
7	T,7,8	12.96	24.48	7.471	73.27	76.95	[1]82.57	[1]42.61	[1]51.97	36.97	3.082
8	T,9	5.318	10.67	3.216	30.22	45.78	46.05	13.01	16.70	13.21	-29.07
9	T,11,17	1.201	2.237	.6847	6.768	5.536	6.916	15.75	17.45	-10.93	-75.57
10	T,12	.02904	.05757	.01739	.1648	.2474	.2368	.1164	.1558	.6066	-.1565
11	T,13	-.02698	-.05352	-.01617	-.1532	-.2306	-.2203	-.1072	-.1435	-.5673	-16.40
12	T,14,15	-.005157	-.01022	-.003088	-.02927	-.04381	-.04199	-.02084	-.02790	-.1070	-3.066
13	T,16	.000020	.000040	.000012	.000114	.000171	.000163	.0000791	.000106	.000422	.01678
14	T,18	-.4857	-.8245	-.2926	-3.004	-16.84	-2.987	-1.172	-1.495	-1.749	-.6918
15	T,20	10.41	16.16	7.463	-41.75	-30.54	-33.04	-21.58	-24.88	-18.84	-7.681
16	SL,7,17	-2.671	-5.145	-1.564	-15.12	-18.08	-18.84	-26.65	-23.53	-22.62	-25.09
17	SL,1,2,3,18,20	-53.41	[1]-78.48	[1]-62.44	-45.00	-35.42	-32.99	-16.11	-19.75	-18.82	-7.500
18	QRE,2,3,4,18,20	25.05	52.49	[1]17.27	[1]65.74	53.82	49.30	26.79	31.93	28.18	11.32
19	QRE,11,13,14,17	3.739	7.291	2.210	21.18	27.77	28.08	24.27	29.18	49.54	[1]113.3
20	QRE,1,5-10,12,15,16,19	[1]269.2	15.07	12.45	36.80	[1]181.1	49.04	27.50	30.81	[1]59.49	[1]162.8

Regression parameter No.	Aquifer property and zone of calibration (pl. 2)	Average sensitivity within each aquifer zone (pl. 2) 11	12	13	14	15	16	17	18	19	20
1	BF,1,4,7,11,13,14,16-20	4.834	12.47	9.525	19.03	17.02	24.95	2.602	55.54	[1]272.6	11.36
2	T,1,19	-.01746	-.01661	-.01608	-.1625	-.01640	-.01637	-.01257	.1864	[1]-164.8	-.3708
3	T,2,3	-13.70	-13.21	-12.73	-12.89	-13.02	-12.99	-9.358	-103.9	-137.2	[1]-162.8
4	T,4	-9.762	-9.427	-9.079	-9.191	-9.291	-9.269	-6.639	7.659	31.14	40.89
5	T,5,10	-.4346	-18.85	-3.042	-8.694	-12.91	-11.93	-.1479	-6.971	.9661	.9960
6	T,6	-2.999	-2.968	-2.835	-2.878	-2.916	-2.907	-1.837	15.34	15.72	17.69
7	T,7,8	-8.361	-6.876	-7.010	-6.967	-6.929	-6.937	-9.051	33.96	59.61	59.19
8	T,9	-9.781	-10.70	-9.897	-10.15	-10.38	-10.33	-3.296	16.92	21.62	22.59
9	T,11,17	[1]-59.37	[1]-110.7	[1]-115.5	-114.4	-112.9	-113.2	-2.812	2.951	5.636	5.560
10	T,12	.8190	-56.77	-19.36	-67.73	-90.16	-85.43	-.05117	.08912	.1212	.1253
11	T,13	-.7040	-79.49	-65.73	[1]-138.2	-119.0	-123.4	.04638	-.08291	-.1126	-.1164
12	T,14,15	-.1405	-18.31	.4551	-84.95	-70.99	-117.0	.009417	-.01581	-.02154	-.02226
13	T,16	.000503	.05498	-.008902	-.08296	.04393	[1]-669.6	-.0000339	.0000615	.000083	.000086
14	T,18	-.3531	-.3430	-.3297	-.3339	-.3377	-.3369	-.2349	[1]-118.9	-1.877	-2.035
15	T,20	-4.546	-4.349	-4.202	-4.249	-4.291	-4.282	-3.206	-4.213	-58.88	-42.30
16	SL,7,17	-26.03	-25.81	-25.78	-25.79	-25.80	-25.80	[1]-26.59	-7.446	-11.82	-11.92
17	SL,1,2,3,18,20	-4.135	-3.986	-3.842	-3.888	-3.930	-3.921	-2.831	-65.54	-49.15	-54.13
18	QRE,2,3,4,18,20	6.363	6.120	5.902	5.972	6.035	6.021	4.396	[1]130.8	68.73	[1]71.53
19	QRE,11,13,14,17	[1]86.93	[1]222.3	[1]190.6	[1]323.0	[1]294.3	311.9	[1]41.33	10.85	16.13	16.45
20	QRE,1,5-10,12,15,16,19	41.39	[1]121.0	72.93	[1]142.4	[1]165.5	[1]854.5	17.68	32.71	-68.40	27.37

[1] Largest sensitivities in each zone.

sensitivity indicate a large influence on calculated head when the parameter value is changed. Largest sensitivity values are footnoted in table 12. For example, model response in zones 1 and 19 is most sensitive to changes in transmissivity and recharge. Although the model generally is sensitive to changes in transmissivity, calculated heads in some zones are most sensitive to the transmissivity of adjacent zones. For example, the largest absolute value of scaled sensitivity in zones 4, 6, 7, 8, and 9 is related to transmissivity in zones 2 and 3 (table 12). Transmissivity, recharge, and boundary flux are strong influences along the margins of the plain (zones 1, 5, 10, 16, 18, and 19). Spring discharges are sensitive to leakance values; this information aided estimation of leakance. Constant flux, represented by the recharge parameter, was a strong influence everywhere except in the central part of the plain (zones 4, 6, 7, and 8), where most lands are undeveloped. Overall, the model was most sensitive to recharge and, in some areas, transmissivity.

Comparison and analysis of regression results are based on the assumption of linearity with respect to aquifer parameters. The technique developed by Cooley (1977, 1979) is nonlinear in transmissivity and leakance; therefore, statistical results are approximations. Cooley (1979) presented a measure of linearity (Na) derived by Beale (1960). This measure is based on the ratio between results of the nonlinear flow equation (2) and those predicted by use of the calculated sensitivities (linearized model). Models are considered definitely nonlinear if:

$$Na > 1/F(K,J-K,\alpha) \qquad (8)$$

where

$F(K,J-K,\alpha)$ = the upper α percent point of the F distribution with K and J-K degrees of freedom,
K = number of regression parameters, and
J = number of head observations.

If Na is less than $0.01/F(K,J-K,\alpha)$, then the model is effectively linear. For run 40, Na = 0.00978, where $0.01/F(14, 810, 0.05) = 0.00585$, which indicates the model is nearly effectively linear, and the bias caused by nonlinearity is a minor component of the statistical results.

Comparison With Previous Studies

Table 13 illustrates the comparison of transmissivity values obtained by run 40 with those obtained by Mundorff and others (1964), Norvitch and others (1969), and Newton

Table 13.--Comparison of transmissivity values with previous studies

[values in feet squared per second; <, less than; >, greater than; --, no data available]

Zone No.	Mundorff and others (1964, pl. 6)	Norvitch and others (1969, p. 37)	Newton (1978, table 16)	This study (run 40)
1	--	--	--	0.2
2	8	11	8	12
3	5	3	8	.06
4	15	15	10	9
5	15	11	30	.5
6	30	20	35	27
7	--	3	<.3	6
8	11	8	2	12
9	8	8	3	.8
10	>30	15	6	1
11	30	50	35	44
12	1	<8	4	.7
13	5	2	25	8
14	15	8	3	9
15	>30	30	9	13
16	--	--	--	.1
17	>30	15	10	44
18	8	3	10	.2
19	--	--	--	.05
20	8	8	8	13

(1978). Mundorff calculated transmissivity by using a flow-net analysis; Norvitch, using analog modeling; and Newton, using a digital numerical model. Transmissivity values from previous studies are the estimated averages in the zones used in the present study. Results of run 40 are similar to results of previous studies in the central plain area (zones 2, 4, 6, 8, 11, 12, 13, 14, 15, 17, and 20). Zone 9 in the central plain area has a much lower value in the present study, probably owing to better head control now available in this area. Along the margins of the plain (zones 3, 5, 10, and 18), transmissivity values determined in the present study are also much lower than those determined in previous studies, owing to better head data.

SUMMARY AND CONCLUSIONS

Results of steady-state numerical simulations indicate a wide range in transmissivity and leakance values for the regional aquifer underlying the eastern Snake River Plain. Model-calculated transmissivity values for the central part of the plain are similar to those reported in previous studies. In several locations, primarily along the margins, model fit was poor, owing primarily to a violation of one or more model assumptions. The regression model is approximately linear, and calculated standard errors of parameters may be used to calculate reasonable ranges of model parameters. Parameter values and ranges can be used as initial estimates for further modeling efforts.

Using a numerical simulation and parameter-estimation technique for ground-water flow studies yields transmissivity values similar to those estimated by other methods. The advantage of the parameter estimation technique is that it has a sound statistical basis and yields values for a complex set of parameters other than transmissivity, for example, recharge rates and leakance.

Alternative models were tested to observe the effects on overall model fit. Model results improved when more zones were added in areas of poor model fit. As the number of regression parameters increased, however, there was an increasing tendency for the model to not converge to a solution or to generate negative values of transmissivity and leakance. Model results also improved when boundary fluxes were increased in areas that initially were modeled as having small fluxes.

Model results improved significantly when zones 1 and 19 (Twin Falls to Burley) were removed. Model fit in these zones was poor owing to violation of model assumptions of

two-dimensional, steady-state flow. Model analysis indicates that results improved when the y-direction transmissivity was simulated as being greater than the x-direction transmissivity.

Use of a different set of head observations demonstrated stability of model results and usefulness of the steady-state approach. Although increased levels of uncertainty for recharge and leakance did not improve overall model fit, they did increase the standard errors of calculated parameters, making the standard errors more reasonable estimates of the parameter variability. The model was most sensitive to changes in recharge and, in some areas, to transmissivities, particularly near the spring discharge area from Milner to King Hill.

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Appendix A

Diversion and Return-Flow Data for Water Year 1980

The purpose of this appendix is to list 1980 water year diversion and return-flow data and data sources for surface-water irrigated areas on the eastern Snake River Plain. Areas shown in figure 8 include surface-water irrigated lands where diversion records are available. Sources of data are:

a. Idaho Department of Water Resources (1980)
b. U.S. Geological Survey (1980)
c. U.S. Bureau of Reclamation, written commun. (1981)
d. Water District 37, 37M (1980)
e. American Falls District No. 2, written commun. (1981)
f. Wytzes (1980)
g. Kjelstrom (1984)
h. Idaho Department of Water Resources, written commun. (1981)

The data source identifier (a-h) is used as a prefix in the following tables for the irrigation areas.

Irrigation Area 1

Diversions from Falls River

Name	Quantity (acre-ft)
Marysville Canal	a 32,900
Farmers Own Canal	a 14,900
Yellowstone Canal	a 2,900
Orme Canal	a 800
Squirrel Creek	a 1,700
Boom Creek	a 800
Conant Creek	a 6,000
Total	60,000
Estimated surface-return flows	= 21,200
Diversions minus surface return	= 38,800

Irrigation Area 2

Diversions from Henrys Fork, Falls River, and Teton River

Name	Quantity (acre-ft)
Silkey	a 5,000
McBee	a 500
Stewart	a 3,000
Pioneer	a 1,600
Wilford	a 52,200
Salem Union	a 60,600
Farmers Friend	a 33,500
Twin Groves	a 41,100
Roxana	a 4,400
North Salem	a 1,900
Pincock Byington	a 4,200
Consolidated Farmers	a 84,300
Cross Cut	a 39,700
Pumps	a 5,400
Total	337,400
Estimated surface-return flows	= 111,900
Diversions minus surface return	= 225,500

Irrigation Area 3

Diversions from Henrys Fork

Name		Quantity (acre-ft)
St. Anthony Union	a	165,100
Last Chance	a	30,800
Dewey	a	5,100
Independent	a	90,700
St. Anthony Union Feeder	a	38,300
Egin	a	112,100
Total		442,100
Estimated surface-return flows	=	63,000
Diversions minus surface return	=	379,100

Irrigation Area 4

Diversions from Falls River and Henrys Fork

Name		Quantity (acre-ft)
Curr	a	14,500
Chester	a	19,000
Falls River	a	55,300
Enterprise	a	20,300
Teton Irrigation	a	24,500
Saurey-Somers	a	4,600
Island Ward	a	7,500
Teton Island Feeder	a	92,300
Pincock-Gardner	a	1,300
Rexburg City	a	5,000
Rexburg Irrigation	a	52,400
Woodmansee-Johnson	a	5,400
Siddoway	a	1,200
McCormick-Rowe	a	400
Bigler Slough	a	800
Pumps	a	400
Total		304,900
Estimated surface-return flows	=	129,600
Diversions minus surface return	=	175,300

Surface-return flows for areas 1-4 were estimated using data reported by Wyztes (1980) for the 1977 water year. Surface-return flows were adjusted for the 1980 water year by assuming that total streamflow depletion for areas 1-4 was equal to the sum of the depletions within the areas, as expressed in the following equation:

$$\text{basin inflow} - \text{basin outflow} = \Sigma(\text{diversions minus surface returns})$$

Therefore, if basin inflow, outflow, and diversions are known, the sum of all returns can be calculated. Knowing the total of all returns, returns reported by Wyztes (1980) were adjusted by a common multiplier to equal the estimated total. Basin inflows for water year 1980 were:

Henrys Fork at Ashton	g	1,102,400	acre-ft
Falls River at Squirrel	g	550,400	acre-ft
Marysville Canal	g	32,900	acre-ft
Yellowstone Canal	g	2,900	acre-ft
Conant Creek	g	61,900	acre-ft
Teton River near St. Anthony	g	559,300	acre-ft
Moody Creek	g	10,800	acre-ft
Total		2,320,600	acre-ft

Basin outflows for water year 1980 were:

Henrys Fork near Rexburg	g	1,491,900	acre-ft
Rexburg Canal drain	g	10,100	acre-ft
Total		1,502,000	acre-ft

Total diversions for areas 1-4 were 1,144,400 acre-ft. Total returns for areas 1-4 were:

Inflow		Outflow		Diversions		Surface returns	
2,320,600	-	1,502,000	-	1,144,400	=	-325,800	acre-ft

Surface-return flows estimated from Wyztes (1980) were:

Area 1	6,000	acre-ft
Area 2	31,600	acre-ft
Area 3	17,800	acre-ft
Area 4	36,600	acre-ft
Total	92,000	acre-ft

The common multiplier is calculated:

$\frac{325,800}{92,000} = 3.54$, and the estimated surface-return flows are:

Area 1	21,200	acre-ft
Area 2	111,900	acre-ft
Area 3	63,000	acre-ft
Area 4	129,600	acre-ft

Irrigation Area 5

Right bank diversions from the Snake River from Heise to Lorenzo

Name		Quantity (acre-ft)
Hill-Pettinger	a	900
Nelson-Corey	a	1,700
Sunnydell	a	47,400
Lenroot	a	41,000
Reid	a	58,500
Texas + Liberty Park	a	79,100
Bannock Jim	a	5,200
Total		233,800
Surface-return flows		
Texas Canal drain	g	19,100
Texas Slough	g	77,200
Bannock Jim Slough	g	8,800
Total		105,100
Diversions minus surface return =		128,700

Irrigation Area 6

Left bank diversions from the Snake River from Heise to Lorenzo

Name		Quantity (acre-ft)
Riley	g	5,100
Anderson	g	93,400
Eagle Rock	g	135,400
Farmers Friend	g	112,900
Enterprise	g	56,500
Dry Bed	g	1,151,200
Nelson	g	700
Mattson-Craig	g	4,300
Pumps	g	700
Willow Creek near Ririe	g	73,500
Total		1,633,700

Irrigation area 6--continued

Surface-return flows

Dry Bed	g	174,500
Spring Creek	g	21,700
Emigrant Creek	g	1,400
Drain	g	700
Anderson waste	g	6,300
Sand Creek	g	6,700
Little Sand Creek	g	3,500
Taylor	g	10,600
Henrys Creek	g	11,100
Willow Creek floodway	g	8,600
Total		245,100

Diversions minus surface return = 1,388,600

Irrigation Area 7

Right bank diversions from the Snake River from below Lorenzo to Shelley

Name		Quantity (acre-ft)
Butte, Market Lake	a	71,600
Bear Trap	a	6,000
Osgood	a	9,300
Clements	a	700
Kennedy	a	3,500
Great Western	a	126,300
Porter	a	80,800
Woodville	a	21,500
McKay South	a	600
Total		320,300

Surface-return flows

Great Western waste	c	400
Great Western waste	c	30,700
Great Western waste	c	25,600
Butte, Market Lake return	c	7,200
Total		63,900

Diversions minus surface return = 256,400

Irrigation Area 8

Left bank diversions from the Snake River from Lewisville to Blackfoot

Name		Quantity (acre-ft)
Idaho	a	295,200
Snake River valley	a	198,000
Blackfoot	a	111,500
Corbett	a	47,500
Nielson-Hansen	a	2,600
Sand Creek at Idaho Falls	c	6,700
Little Sand Creek at Ammon	c	3,500
Taylor	c	10,600
Henrys Creek	c	11,100
East Idaho Slough	c	13,800
Total		700,500

Surface-return flows

Cedar Point to Reservation Canal	c	2,700
Snake River valley waste to Reservation Canal (estimated)		20,000
Sand Creek to Reservation Canal	c	78,200
Idaho Canal to Blackfoot River	c	30,600
Shull Lateral waste	c	2,200
End of East Idaho Slough into Blackfoot River	c	25,500
Corbett Slough waste to Snake River	c	3,200
Blackfoot Canal waste to Snake River	c	10,200
Total		172,600
Diversions minus surface return	=	527,900

Irrigation Area 9

Diversions from the Snake and Blackfoot Rivers

Name		Quantity (acre-ft)
Little Indian Creek	c	10,500
Fort Hall Main	c	178,900
Fort Hall North	c	70,200
Total		259,600

Irrigation area 9--continued

Surface-return flows

End of Fort Hall North	c	2,500
End of Gibson	c	2,100
Teak Lateral to Ross Fork	c	600
Indian Lateral to Ross Fork	c	700
Ross Fork below Fort Hall Main	c	3,600
Tyhee waste to Ross Fork	c	13,000
Reider waste	c	2,000
Dubois Lateral waste	c	800
Tyhee Lateral waste	c	2,000
Church Lateral waste	c	2,700
End of Fort Hall Main	c	2,300
Total		32,300
Diversions minus surface return =		227,300

Irrigation Area 10

Right bank diversions from the Snake River below Shelley to Blackfoot

Name		Quantity (acre-ft)
New Lava Side	a	35,200
Peoples	a	109,000
Aberdeen-Springfield	a	312,000
Riverside	a	33,600
Danskin	a	58,800
Trego	a	17,700
Wearyrick	a	18,500
Watson	a	31,400
Parsons	a	14,500
Total		630,700

Surface-return flows

Riverside waste	c	15,500
Watson Slough waste	c	9,400
Peoples waste	c	8,700
Duncan waste	c	5,200
New Lava Side waste	c	4,500
Parsons waste	c	1,900
Crawford waste	c	2,400
Total		47,600
Diversions minus surface returns minus canal loss (Aberdeen-Springfield) = 583,100 - 95,200 =		487,900

Irrigation Area 11

Left bank diversions from Portneuf River

Name		Quantity (acre-ft)
Fort Hall Michaud	c	30,600
Falls Irrigation	c	23,200
Bannock Creek	g	54,600
Total		108,400
Surface-return flows		
Bannock Creek	g	34,500
Diversions minus surface return		= 73,900

Irrigation Area 12

Right bank diversion from the Snake River at Lake Walcott

		Quantity (acre-ft)
Diversion	a	385,900
Surface return	g	47,400
Diversion minus surface return		338,500

Irrigation Area 13

Right bank diversion from the Snake River at Lake Milner

		Quantity (acre-ft)
Diversion	g	50,500
Surface return	g	1,700
Diversion minus surface return		48,800

Irrigation Area 14

Right bank diversions from the Snake River at Lake Milner

Name		Quantity (acre-ft)
Northside Twin Falls	a	697,300
Northside Crosscut-Gooding	g	354,200
Northside "A" Lateral	a	18,100
PA Lateral	a	15,200
Total		1,084,800
Surface-return flows	g	62,700
Diversions minus surface return =		1,022,100

Irrigation Area 15

Left bank diversions from the Snake River at Lake Milner

Name		Quantity (acre-ft)
Southside Twin Falls	a	1,090,200
Salmon Falls	b	85,400
Rock Creek	g	25,000
Dry Creek	g	9,000
Cedar Creek	g	8,300
Cottonwood, McMullen, Deep Creeks	g	15,000
Total		1,232,900
Surface-return flows	g	575,600
Diversions minus surface return =		657,300

Irrigation Area 16

Left bank diversion from the Snake River at Lake Milner

		Quantity (acre-ft)
Diversion	g	61,100
Surface return	g	500
Diversion minus surface return		60,600

Irrigation Area 17

Left bank diversion from the Snake River at Lake Walcott

		Quantity (acre-ft)
Diversion	a	312,300
Surface return	g	66,500
Diversion minus surface return		245,800

Irrigation Area 18

Goose Creek diversion from Goose Creek Reservoir

		Quantity (acre-ft)
Diversion	b	44,900
Surface return		0
Diversion minus surface return		44,900

Irrigation Areas 19-26

Milner-Gooding Canal, Big Wood and Little Wood Rivers

Records of measured flows in areas 19-26 are in the Water District 37, 37M (1980) Watermaster report, American Falls District No. 2 report, and the U.S. Geological Survey (1980) report. The approach used in these areas was to sum the inflow and outflow for each area and determine the difference. This approach includes river, canal losses, and field seepage. The total consumed in the basin was compared with the total consumed in six of the eight subbasin areas.

Name		Quantity (acre-ft)
Inflow:		
Big Wood below Magic Reservoir	b	314,100
Little Wood near Carey	b	140,500
Silver Creek at Sportsman Access	b	114,100
Milner-Gooding above Little Wood	b	335,400
X Canal	d	101,100
Total		1,005,200

Irrigation Areas 19-26--continued

Outflow:		
Big Wood near Gooding	b	202,200
Y Canal	d	47,600
X Canal	d	22,200
Dietrich Canal	d	56,700
Total		328,700
Basin inflow minus basin outflow =		676,500

Total of subbasin consumption:

Area	Inflow-Outflow (acre-ft)
19	67,100
20	62,600
21	226,100
22	106,800
25	94,700
26	129,200
Total	686,500

$$\frac{686,500 - 676,500}{686,500} \times 100 = 1.5 \text{ percent difference}$$

Irrigation Area 19

South Gooding tract

Name		Quantity (acre-ft)
Inflow:		
Little Wood at Shoshone	d	168,700
X Canal	d	101,100
Big Wood River near Gooding No. 9	d	69,300
Total		339,100
Outflow:		
Big Wood River near Gooding No. 21	d	202,200
Y Canal	d	47,600
Z Canal	d	22,200
Total		272,000
Inflow minus outflow =		67,100

Irrigation Area 20

North Gooding tract

Name		Quantity (acre-ft)
Inflow:		
Head of North Gooding Main	d	62,600
Outflow:		0
Inflow minus outflow =		62,600

Irrigation Area 21

Shoshone tract

Name		Quantity (acre-ft)
Inflow:		
Big Wood River below Diversion No. 5	d	164,700
Milner-Gooding Canal below Little Wood River	d	193,300
Total		358,000
Outflow:		
Head of North Gooding Main	d	62,600
Big Wood River near Gooding No. 9	d	69,300
Total		131,900
Inflow minus outflow =		226,100

Irrigation Area 22

Lower Little Wood River

Name		Quantity (acre-ft)
Inflow:		
Little Wood River near Richfield, nonirrigation season--estimated from historic records	g	60,000
Little Wood River near Richfield, irrigation season	d	65,400
JB Slough near Richfield	d	40,300
Marley Slough	d	20,300
Historic F-waste	h	4,100
Milner-Gooding Canal above Little Wood	d	335,400
Total		525,500

Irrigation area 22--continued

Outflow:		
Dietrich Canal No. 11	d	56,700
Milner-Gooding Canal below Little Wood	d	193,300
Little Wood at Shoshone	d	168,700
Total		418,700
Inflow minus outflow =		106,800

Irrigation Area 23

Dietrich tract

Name		Quantity (acre-ft)
Inflow:		
Head of Dietrich Canal	d	56,700
Milner-Gooding diversion	e	16,600
Total		73,300
Outflow:		
Historic F-waste	h	4,100
Inflow minus outflow =		69,200

Irrigation Area 24

Hunt tract

		Quantity (acre-ft)
Inflow:	e	36,000
Outflow:		0
Inflow minus outflow =		36,000

Irrigation Area 25

Richfield tract

Name		Quantity (acre-ft)
Inflow:		
Head of Richfield Canal	d	159,300
Outflow:		
JB Slough near Richfield	d	40,300
Marley Slough	d	20,300
Sum of miscellaneous wastes	h	4,000
Total		64,600
Inflow minus outflow =		94,700

Irrigation Area 26

Silver Creek, Upper Little Wood diversions

Name		Quantity (acre-ft)
Inflow:		
Silver Creek at Sportsman Access	b	114,100
Little Wood near Carey	b	140,500
Total		254,600
Outflow:		
Little Wood near Richfield, nonirrigation season--estimated from historic records		60,000
Irrigation season	d	65,400
Total		125,400
Inflow minus outflow =		129,200

APPENDIX B

Parameter Estimation Program Documentation

Introduction

This program documentation is based on materials authored by Steven P. Larson in March 1979, revised by James V. Tracy in September 1980, and distributed as instruction material for the course, "Parameter-Estimation Techniques for Ground-Water Models," held at U.S. Geological Survey's National Training Center in Denver, Colo., September 15-26, 1980. Mr. Larson and Mr. Tracy are not responsible for errors or mistakes that may be present.

The program is designed to perform a nonlinear regression analysis to compute parameters associated with a finite-difference model of a steady-state, two-dimensional, ground-water flow system. The theory of the regression analysis is described by Cooley (1977) and the computer program follows his development explicitly.

The computer program is composed of a main program and seven subroutines. The main program controls input-output and performs all computations that cannot be accomplished more effectively with subroutines. The seven subroutines (D4SOLVE, COEF, LSTSQ, PRTOT, ORDER, ARRAY, ARRAYI) perform the following specialized tasks:

D4SOLVE - Solves the sets of linear algebraic equations resulting from the application of finite-difference methods by LDU factorization assuming the equations are ordered in an alternating diagonal fashion.

COEF - Computes coefficients necessary for the determination of transformed sensitivities and the flow equation.

LSTSQ - Computes the coefficients of the normal equations and solves the system of equations to determine the vector of parameter change coefficients.

PRTOT - Prints matrices or vectors in a column configuration.

ORDER - Computes equation numbers at grid points corresponding to the alternating diagonal ordering scheme.

ARRAY - Loads and/or prints one- and two-dimensional array variables.

ARRAYI - Loads and/or prints one- and two-dimensional integer array variables.

The basic flow of the main program can be described as follows:

(A) Data input and variable initialization are accomplished.

(B) An initial solution corresponding to the initial parameter estimates is computed.

(C) In an iterative fashion, the following four steps are taken until the regression technique converges or until the number of iterations exceeds the maximum allowed.

(1) Compute residual of current estimate of head by invoking D4SOLVE subroutine.

(2) Compute transformed sensitivities using decomposed coefficient matrix and other coefficients computed by COEF subroutine.

(3) Invoke LSTSQ to form and solve normal equations.

(4) Update parameters using parameter change coefficients generated by LSTSQ subroutine.

(D) Various statistics associated with the regression analysis are computed.

(E) Mass balances are computed.

Aquifer Zonation and Variable Definition

The finite-difference grid is divided into zones that form the basic element for the regression analysis. An aquifer property, such as transmissivity or leakance, at a particular node is computed as the product of the zonal value of the property times the nodal value of the property. Thus, if all nodal values for a property are given a value of unity, the zonal value becomes the value of the property for each node within that zone. Variation of a property within a zone is accomplished by assigning cell values that describe the relative variation within the zone. The zonal value then becomes a scalar for these relative values.

Thus, the transmissivity of cell (i,j) that is part of zone k is $TRAN_{k\ (X\ or\ Y)}\ T_{ij}$, where $TRAN_{k\ (X\ or\ Y)}$ is the zonal value and T_{ij} is the block value.

The zonal properties of one or more zones can be grouped to form a single parameter of the regression analysis. Computed changes in a regression parameter are applied equally to the zonal property of all zones that form that regression parameter. Nodal values of a property are unaffected by the regression procedure. The definitions of some of the more important variables in the computer program related to aquifer properties follow:

Variable name	Definition
TRANX, TRANY, VLEAK, QDIST	Zonal values of transmissivity (X and Y), leakance, and distributed recharge.
IZN	An integer array that indicates the zone number of each block.
T, SL, QRE	Block values of transmissivity, leakance, and distributed recharge.
HR	Head on the boundary of the confining bed opposite the aquifer.
WELL	Block values of discharge (or recharge) from wells or other constant-rate source-sink phenomena.

Boundary Conditions and Boundary Parameters

Two types of boundary conditions may be used; specified flow and/or specified head. Both may be considered as regression parameters. Non-zero specified flow boundaries are imposed by assigning the appropriate value of the specified flow rate to the nodal value of WELL. Specified head boundaries are imposed by assigning a negative integer to variable IN corresponding to each node that is to be considered as specified head. The value of the known head at these nodes is entered via variable HO, which also describes nodal values of observed head.

Additional variables are used if specified flow or specified head boundary conditions are to be considered as regression parameters. Variables IBZN and QBND are used to

indicate groups of nodes that form a specified flow regression parameter and the value of the parameter. Thus, for a particular specified flow regression parameter, the number of the parameter is entered into variable IBZN corresponding to the node or group of nodes that forms a specified flow zone. The specified flow for each node within a zone is the product of QBND for that zone and a multiplier for the node. QBND is modified by the regression procedure; the multiplier is unaffected.

Specified head boundary nodes that are to be considered regression parameters are defined in groups. Each group (variable IZ) is composed of a sequence of nodes (variables IH and JH). The specified head of the first and last nodes in the sequence will be regression parameters (BH) or a single regression parameter. Adjustments to these nodes computed by the regression procedure are apportioned to other nodes in the sequence. The proportion is the ratio of (A) the distance (along the sequence of nodes) from the end node to the node of interest, to (B) the distance between the two end nodes. These factors are computed by the program for a given sequence.

Prior Information on Regression Parameters

If estimates of the regression parameters are available from other sources (for example, aquifer tests), it may be desirable to introduce the information (parameter estimates and variability) into the regression analysis. The variability of the estimate is represented by a normalized standard error. Variable RK is used to store these values for aquifer parameters (TRANX, TRANY, VLEAK, and QDIST) and for specified head and flow boundary parameters (BH and QBND). The values are read directly into variable RK except for specified head boundary parameters. These are read into variables STEHA and STEHB for each boundary segment, and appropriate elements of variable RK are set equal to these values.

The use of prior information requires an estimate of the error variance of the heads computed with the optimum parameters (variable EV). This estimate may be obtained from a solution that did not use prior information. If the estimate differs substantially from the value computed by the analysis using prior information, the problem should be re-solved using that computed value as the estimate of error variance.

Solution Only Mode

To facilitate the calculation of certain statistical measures, the program is capable of bypassing the regression analysis and computing only head distributions for various combinations of parameter values. This is accomplished by specifying the "solution only" option (variable ISO) and providing the various combinations of parameter values for which solutions are desired. These solutions can be used to test the assumption of model "linearity" in the vicinity of the optimum parameter estimates.

Using the Program

The computer code has been designed to be as machine independent as possible. Also, to minimize confusion, all arrays have been dimensioned explicitly. The following summarizes the minimum dimensions required for the program to operate properly for a specific problem.

If

N_o is the number of observed heads,

N_g is the number of grid points (N_x x N_y),

N_x is the number of grid columns,

N_y is the number of grid rows,

N_e is the number of active nodes in the grid,

N_z is the number of aquifer parameter zones in the model grid,

N_p is the number of regression parameters for aquifer zones (excluding boundary parameters),

N_q is the number of specified flow boundary parameters,

N_h is the number of specified head boundary parameters,

N_{qp} is the total number of nodes on boundary where flow is a parameter,

N_{hp} is the total number of nodes on boundary where head is a parameter, and

N_R is the total number of regression parameters, $N_p + N_q + N_h$,

then the array variables should be dimensioned as follows:

Variable name	Dimension[1/]
WELL, HR, W, HC, HO	N_g
T, QRE, SL	$(N_x-1)(N_y-1)$ unchecked values
IZN	N_g
IBZN	N_{bp}
TRANX, TRANY, VLEAK, QDIST	N_z
IPRM	4, N_z
QBND, BH	N_q+N_h
DX	N_x
DY, JPOS	N_y
RK, P	N_R
B	$4N_R$
S	N_R, N_e
A	N_R, N_R
V	N_e
IBPA, IBPB	$N_{hp}+N_{qp}$
ILOC, JLOC	N_g
PLA, PLB	N_{hp}
QBF	N_{qp}
IC, AU	5, $N_e/2$
AL	N_y-1, $N_e/2$
IN	N_g
QBND	N_q
BH	N_h
HCA	5, N_o

[1/] These dimensions are approximate. The exact sizes required are calculated and printed in subroutine ORDER.

Note that array variables that have a single dimension (TRANX, TRANY, T, HO, etc.) and are passed to subroutines need only be dimensioned as "one" within the subroutine (only the initial address of an array is actually "passed" to a subroutine and dimension sizes are required only for multi-dimensioned arrays). This "unit" dimension need not be changed (in the subroutine) if the dimension of the variable is changed in the main program. Unit dimensions in subroutines cannot be used for multidimensioned arrays.

Input Data

Cards 1-3 - TITLE (Format, 20A4)

Card 4 - Problem size parameters (Format, 16I5)

Card columns	Variable	Definition
1-5	ID	Number of grid columns
6-10	JD	Number of grid rows
11-15	NZNS	Number of aquifer parameter zones
16-20	NWELS	Number of wells
21-25	NQBND	Number of specified flow zones
26-30	NBQZ	Number of specified flow boundary parameters
31-35	NBHZ	Number of specified head boundary zones
36-40	NBHP	Number of specified head boundary parameters
41-45	NPAR	Number of regression parameters associated with aquifer zones
46-50	NUM	Maximum number of iterations allowed for the regression analysis
51-55	IPRX	Additional print sensitivities and orthogonalize sensitivities option. Code 1 to select
56-60	IRPF	Option for optimal bias parameter calculation. Code 1 to select
61-65	IPO	Additional printout option. Code 1 to select
66-70	ISO	Head solutions only option. Code 1 to select
71-75	NONMB	Number of nodes for mass balance calculations; limit = 200

Card 5 - Special regression parameters (Format, 8F10.0)

Card columns	Variable	Definition
1-10	AP	Acceleration parameter for regression analysis (normally equal to 1.0)
11-20	AMP	Marquardt parameter. Code 0.0 if not used
21-30	RP	Ridge parameter for regression analysis (normally equal to 0.0)
31-40	RPF	Bias parameter for regression. Set to 0.0
41-50	EV	Estimated error variance for problems using prior information. Code 0.0 if not used

Array sets 1-9 - Aquifer description arrays (Format, 2I5)
Each array set, 1-10, is prefaced by a single parameter card containing the following information:

Card columns	Variable	Definition
1-5	NOZN	Number of rectangular input zones into which the variable has been subdivided
6-10	IPRN	Print option for full array. Set to 0 for print. Set to 1 for no output

Each input zone (1, NOZN) of array sets, 1-8, is prefaced by a parameter card providing the following information about that input zone:

(Format 4I5, F10.0, I5)

Card columns	Variable	Definition
1-5	IB	Beginning column of the rectangular input zone
6-10	IE	Final column of the rectangular input zone

11-15	JB	Beginning row of the rectangular input zone
16-20	JE	Final row of the rectangular input zone
21-30	FACT	If the array set is uniform for the entire zone, FACT is the cell or nodal value that is assigned to each grid point. If the array set is not uniform, each cell or nodal value on the subsequent data cards will be multiplied by FACT
31-35	IVAR	Code 0 if the array set is uniform. Code 1 if it is not uniform

Each input zone (1, NOZN) of array sets, 9-10, is prefaced by a parameter card providing the following information about that input zone:

(Format, 6I5)

Card columns	Variable	Definition
1-5	IB	Beginning column of the rectangular input zone
6-10	IE	Final column of the rectangular input zone
11-15	JB	Beginning row of the rectangular input zone
16-20	JE	Final row of the rectangular input zone
21-25	IFACT	If the array set is uniform for the entire zone, FACT is the cell or nodal value that is assigned to each grid point. If the array set is not uniform, each cell or nodal value on the subsequent data cards will not be multiplied by IFACT
26-30	IVAR	Code 0 if the array set is uniform. Code 1 if it is not uniform

The format for the data cards is variable and is given for each array set in the following list. Remember that data cards are not required if the array set is uniform for the entire zone (IVAR = 0). The following lists the array sets in the order in which they must appear:

Array set number	Variable	Format	Definition
1	DX(ID-1)	8F10.0	Distance between grid points in x (I) direction
2	DY(JD-1)	8F10.0	Distance between grid points in y (J) direction
3, 4	NHCA	I5	Number of head observations
	HCA (4, NHCA)	5F10.2	HCA(1, N) x location in nodal units HCA(2, N) y location in nodal units HCA(3, N) water level HCA(4, N) weighting value HCA(5, N) interpolated head, set to 0.0
5	T(ID-1, JD-1)	8F10.0	Transmissivity
6	SL(ID-1, JD-1)	8F10.0	Leakance (k'/m') of confining bed
7	HR(ID, JD)	8F10.0	Head on boundary of confining bed opposite the aquifer
8	QRE(ID-1, JD-1)	8F10.0	Recharge rate per unit area
8b	(NLMBX, NLMBY)	(I5,5x,I5)	X, Y locations of mass balance nodes, NONMB cards
9	IZN(ID-1, JD-1)	16I5	Zone number of each cell. Each active grid point ($T \geq 0$) must have a zone number

Card set 1 - Zonal parameters (Format, I5, 4F10.0). Set will contain NZNS cards.

Card columns	Variable	Definition
1-5	I	Zone number
6-15	TRANX(I)	Zonal X-transmissivity value for zone I
16-25	TRANY(I)	Zonal Y-transmissivity value for zone I

26-35	VLEAK(I)	Zonal leakance value for zone I
36-45	QDIST(I)	Zonal distributed recharge value for zone I

Card set 2 - Parameter numbers (Format, 16I5). Set will contain NZNS cards.
OMIT if NPAR = 0

Card columns	Variable	Definition
1-5	I	Zone number
6-10	IPRM(1, I)	Parameter number for X-transmissivity in zone I. Code 0 if it is not a regression parameter
11-15	IPRM(2, I)	Parameter number for Y-transmissivity in zone I. Code 0 if it is not a regression parameter
16-20	IPRM(3, I)	Parameter number for leakance in zone I. Code 0 if it is not a regression parameter
21-25	IPRM(4, I)	Parameter number for distributed recharge in zone I. Code 0 if it is not a regression parameter

Note: The cards in each set (1 or 2) may appear in any order with respect to zone number, but there must be NZNS cards.

Card set 3 - Normalized parameter standard errors (Format, 8F10.0). Eight values per card; NPAR values. Use as many cards as required.
OMIT NPAR = 0

Card columns	Variable	Definition
1-10 11-20	RK(1) RK(2) RK(NPAR)	Normalized standard errors (standard error divided by initial parameter value) for each parameter. Enter values for parameters defined by IPRM (aquifer zone parameters) in increasing order. Code if 0.0 no prior information exists for the parameter

Card set 4 - Well rates (Format, 2I5, F10.0). Set will contain NWELS cards. Omit if NWELS is zero.

Card columns	Variable	Definition
1-5	I	Column location of well
6-10	J	Row location of well
11-20	WELL(I, J)	Well rate, negative for withdrawal

Each flow boundary segment (zone) is identified and quantified by the following data set 1, card set 5, which gives the particular information regarding each zone.

Card set 5 - Specified flow boundary zone parameters (Format, 5I5, 3F10.0)
Requires the following; NQBND cards for zonal information. One card for each zone (1, NQBND); if NQBND = 0, omit the data set.

Card columns	Variable	Format	Definition
1-5	IA	I5	Column location of the A end of the segment (zone)
6-10	JA	I5	Row location of the A end of the segment (zone)
11-15	IB	I5	Column location of the B end of the segment (zone)
16-20	JB	I5	Row location of the B end of the segment (zone)
21-25	IZ	I5	Parameter number (set equal to zero if not a parameter)
26-35	QBND	F10.0	Flow parameter value
36-45	RK	F10.0	Normalized parameter standard error
46-55	QBM	F10.0	Multiplier for flow parameter

Array set 10 - Specified head boundary zonation

Array set number	Variable	Format	Definition
10	IBZN(ID, JD)	16I5	To denote specified heads. Set to -1

Card set 6 - Specified head boundary parameter information. This set is composed of one card (6a) with descriptive information about the boundary segment or zone followed by a card or cards (6b) that describe the row and column locations of the nodes that form the segment. There will be NBHZ groups of card set 6. If NBHZ is zero, all cards are omitted.

Card 6a - Segment description (Format, 4I5, 2F10.0)

Card columns	Variable	Definition
1-5	IZ	Segment or zone number
6-10	NN	Number of nodes in the segment
11-15	IBPA	Specified boundary parameter number for A end of segment
16-20	IBPB	Specified boundary parameter number for B end of segment
21-30	STEHA	Normalized standard error of head at A end of segment
31-40	STEHB	Normalized standard error of head at B end of segment

Card(s) 6b - Nodes forming segment IZ (Format, 2I5, F10.0)

Card columns	Variable	Definition
1-5	IH	Column location of node
6-10	JH	Row location of node
11-20	V	Estimated head at node IH, JH

Note: For card(s) 6b, estimated heads (V) are required only at the ends of the segment (A and B). If estimated heads for the other nodes in the segment are set equal to zero, a

linear interpolation (based on distance) will be made from the end point values to determine the initial head estimate at these nodes. If non-zero values are entered, the initial head estimate will be the non-zero value. Regression parameters (changes in head) are calculated only for the end points and are distributed linearly to zero from one end point to the other end point. The change in head at any other node point in the segment will thus have two components; a percentage of the computed change at each of the end points. If IBPA is the same as IBPB, the computed head change at both ends of the segment will be the same and, in effect, a single head change will be applied to all nodes in the segment.

The following cards and card sets are required only if the solution only option (ISO, card 4) is specified. Mass balance calculations are not performed in the solution only option.

Card 6 - Additional solution specification (Format, I5)

Card columns	Variable	Definition
1-5	N	Number of solutions required using alternative parameter sets. (Code 0 if a solution is desired only for the initial set of parameters)

Card set 7 - Zonal parameters for next parameter set (Format, I5, 4F10.0). Set will contain NZNS cards.

Card columns	Variable	Definition
1-5	I	Zone number
6-15	TRANX(I)	Zonal X-transmissivity parameter for zone I
16-25	TRANY(I)	Zonal Y-transmissivity parameter for zone I
26-35	VLEAK(I)	Zonal leakance parameter for zone I
36-45	QDIST(I)	Zonal distributed recharge parameter for zone I

Note: The zones may appear in any order, but all zones must be defined.

Card set 8 - Specified flow boundary parameters for next parameter set (Format, I5, F10.0). Set will contain NBQZ cards. Omit if NBQZ is zero.

Card columns	Variable	Definition
1-5	I	Specified flow boundary zone number
6-15	QBND(I)	Specified flow boundary parameter for zone I

Note: The zones may appear in any order, but all zones must be defined if NBQZ is not zero.

Card set 9 - Specified head boundary parameters for next parameter set (Format, I5, F10.0). Set will contain NBHP cards. Omit if NBHZ is zero.

Card columns	Variable	Definition
1-5	I	Specified head boundary parameter number
6-15	BH(I)	Fractional change of specified head boundary parameter I. The head computed for the first solution is the basis for computing the values for subsequent solutions

Note: The parameters may appear in any order, but all parameters must be defined if NBHZ is not zero.

Card sets 7, 8, and 9 will be repeated N times. The program will compute and print the solution corresponding to each set of parameters. This will be useful in determining certain statistical measures about the regression analysis.

Appendix C

Modified Parameter Estimation Program

```
C       FINITE DIFFERENCE PROGRAM FOR NONLINEAR REGRESSION SOLUTION      000100
C       OF TWO-DIMENSIONAL, STEADY-STATE, GROUND-WATER FLOW PROBLEMS     000110
C       BY R. L. COOLEY, USGS, DENVER, COLO.                             000120
C       MODIFIED BY S. GARABEDIAN TO USE NON-NODAL OBSERVATION HEADS     000130
C                                                                        000140
C                                                                        000150
      PROGRAM MAIN(TAPE4,TAPE5,TAPE6,TAPE7,TAPE8,INPUT,OUTPUT)           000160
      DIMENSION TITLE(20),DX(60),DY(30),T(1400),SL(1400),QRE(1400)       000170
     1,WELL(1400),HR(1400),DUM(1400),HC(1400),TRANX(50),TRANY(50)        000180
     2,VLEAK(50),QDIST(50),P(50),RK(50),QBND(10),QBF(150),BH(30),PLA(150000190
     3)                                                                 000200
     4,PLB(150),S(20,1100),V(1400)                                      000210
      DIMENSION A(20,20),AU(5,550),AL(30,500)                           000220
      DIMENSION HCA(5,1100)                                             000230
      DIMENSION NLMA(400),NLMB(400),XLMB(400)                           000240
      DIMENSION JPOS(30),IZN(1400),IBZN(1400),IPRM(4,50),IBPA(150),IBPB(000250
     1150)                                                              000260
     2,ILOC(1400),JLOC(1400),IN(1400),IC(5,550)                         000270
      COMMON/INT/NIJ,NEQ,ICR,ICR1,IB1,LH1,ID,JD,IM,JM,NVAR,NQSD,NBPAR   000280
     1,NVA2,NVA3,IPO,KOUNT,INDT,IBHZ                                    000290
      COMMON/TNME/IIN,IOUT                                              000300
      COMMON/FLT/AU,AL,AP,AMP,RP,RPF,YSQ                                000310
      EQUIVALENCE (ILOC(1),TITLE(1),AU(1,1)),(JLOC(1),AL(1,1),A(1,1))   000320
C**DEFINE INPUT AND OUTPUT FILES, AND ARRAY DIMENSIONS                   000330
      IIN=7                                                             000340
      IOUT=6                                                            000350
      NVE=20                                                            000360
C**READ AND WRITE 3 TITLE CARDS                                         000370
      WRITE(IOUT,804)                                                   000380
      DO 5 I=1,3                                                        000390
      READ(IIN,801) (TITLE(J),J=1,20)                                   000400
    5 WRITE(IOUT,803) (TITLE(J),J=1,20)                                 000410
C**READ JOB SPECIFICATION DATA                                          000420
      READ(IIN,800) ID,JD,NZNS,NWELS,NQBND,NBQZ,NBHZ,NBHP,NPAR,NUM,IPRX 000430
     1,IRPF,IPO,ISO,NONMB                                               000440
      WRITE(IOUT,802) ID,JD,NZNS,NWELS,NQBND,NBQZ,NBHZ,NBHP,NPAR,NUM    000450
     1,IPRX,IRPF,IPO,ISO                                                000460
      READ(IIN,820) AP,AMP,RP,RPF,EV                                    000470
      WRITE(IOUT,806) AP,AMP,RP,RPF,EV                                  000480
C**READ INITIAL ARRAY DATA                                              000490
      IM=ID-1                                                           000500
      JM=JD-1                                                           000510
      CALL ARRAY(DX,IM,1,1,0)                                           000520
      CALL ARRAY(DY,JM,1,2,0)                                           000530
      NIJ=ID*JD                                                         000540
      DO 14 I=1,NIJ                                                     000550
   14 HC(I)=0.0                                                         000560
C*MODIFICATION* READ IN THE LOCATION, VALUE AND WEIGHTING OF            000570
C               OBSERVATION HEADS                                       000580
      READ(IIN,12)NHCA                                                  000590
      DO 11 I=1,NHCA                                                    000600
      READ(IIN,13)(HCA(J,I),J=1,5)                                      000610
      IX=INT(HCA(1,I))                                                  000620
```

```
      IY=INT(HCA(2,I))                                                  000630
      I1=(IY-1)*ID+IX                                                   000640
      HC(I1)=HCA(3,I)                                                   000650
      HC(I1+1)=HCA(3,I)                                                 000660
      HC(I1+ID)=HCA(3,I)                                                000670
      HC(I1+ID+1)=HCA(3,I)                                              000680
   11 CONTINUE                                                          000690
C*MODIFICATION*   RESET CONSTANT HEADS                                 000700
      DO 15 I=1,NHCA                                                    000710
      IF(HCA(4,I).GE.0.0)GO TO 15                                       000720
      IX=INT(HCA(1,I))                                                  000730
      IY=INT(HCA(2,I))                                                  000740
      I1=(IY-1)*ID+IX                                                   000750
      HC(I1)=HCA(3,I)                                                   000760
      HCA(4,I)=0.0                                                      000770
   15 CONTINUE                                                          000780
   12 FORMAT(3I5)                                                       000790
   13 FORMAT(F10.0,F10.0,3F10.0)                                        000800
      CALL ARRAY(T,IM,JM,5,0)                                           000810
      CALL ARRAY(SL,IM,JM,6,0)                                          000820
      CALL ARRAY(HR,ID,JD,7,0)                                          000830
      CALL ARRAY(QRE,IM,JM,8,0)                                         000840
C*MODIFICATION* READ IN NODAL LOCATIONS WHERE MASS BALANCE              000850
C               CALCULATIONS ARE TO BE MADE                            000860
      IF(NONMB.EQ.0)GO TO 41                                            000870
      DO 43 I=1,NONMB                                                   000880
   43 READ(IIN,44)NLMB(I*2-1),NLMB(I*2)                                 000890
   44 FORMAT(I5,5X,I5)                                                  000900
      DO 42 I=1,NONMB                                                   000910
      NLMA(I)=NLMB(2*I-1)+(NLMB(2*I)-1)*ID                              000920
   42 XLMB(I)=0.0                                                       000930
   41 CONTINUE                                                          000940
C**READ GRID ZONATION                                                  000950
      CALL ARRAYI(IZN,IM,JM,1,0)                                        000960
C**READ INITIAL ZONAL PARAMETERS                                       000970
      WRITE(IOUT,810)                                                   000980
      DO 30 J=1,NZNS                                                    000990
      READ(IIN,812) I,TRANX(I),TRANY(I),VLEAK(I),QDIST(I)               001000
      WRITE(IOUT,814) I,TRANX(I),TRANY(I),VLEAK(I),QDIST(I)             001010
      IF(ISO.GT.0)WRITE(8,814)I,TRANX(I),TRANY(I),VLEAK(I),QDIST(I)     001020
      DO 20 K=1,4                                                       001030
   20 IPRM(K,J)=0                                                       001040
   30 CONTINUE                                                          001050
C**READ AND PRINT PARAMETER #'S                                        001060
      NBPAR=NBHP+NBQZ                                                   001070
      IF(NPAR.LE.0) GO TO 45                                            001080
      WRITE(IOUT,816)                                                   001090
      DO 40 J=1,NZNS                                                    001100
      READ(IIN,800) I,(IPRM(K,I),K=1,4)                                 001110
      WRITE(IOUT,818) I,(IPRM(K,I),K=1,4)                               001120
      DO 35 K=1,4                                                       001130
   35 IPRM(K,I)=IPRM(K,I)+NBPAR                                         001140
   40 CONTINUE                                                          001150
```

```
C**    READ AND PRINT PARAMETER COEFFICIENTS OF VARIATION                001160
       READ(IIN,820) (RK(K+NBPAR),K=1,NPAR)                              001170
       WRITE(IOUT,822)                                                   001180
       CALL PRTOT(RK(NBPAR+1),NPAR,1)                                    001190
    45 JPOS(1)=0                                                         001200
       DO 50 J=2,JD                                                      001210
    50 JPOS(J)=JPOS(J-1)+ID                                              001220
C**READ WELL DATA                                                        001230
       DO 55 N=1,NIJ                                                     001240
    55 WELL(N)=0.                                                        001250
       IF(NWELS.LE.0) GO TO 61                                           001260
       WRITE(IOUT,824)                                                   001270
       DO 60 K=1,NWELS                                                   001280
       READ(IIN,826) I,J,WELL(I+JPOS(J))                                 001290
       WRITE(IOUT,828) I,J,WELL(I+JPOS(J))                               001300
    60 CONTINUE                                                          001310
C** READ AND FORM ARRAYS FOR SPECIFIED POINT OR LINE FLUXES              001320
    61 NQSD=0                                                            001330
       IF(NQBND.LE.0) GO TO 85                                           001340
       WRITE(IOUT,830)                                                   001350
       N=0                                                               001360
       DO 80 J=1,NQBND                                                   001370
       READ(IIN,832) IA,JA,IB,JB,IZ,QB,STDER,QBM                         001380
       WRITE(IOUT,831) IA,JA,IB,JB,IZ,QB,STDER,QBM                       001390
       M=1                                                               001400
       K=IA-1                                                            001410
       IF(JA.EQ.JB) GO TO 62                                             001420
       M=ID                                                              001430
       K=JA-1                                                            001440
    62 MA=IA+JPOS(JA)                                                    001450
       MB=IB+JPOS(JB)-M                                                  001460
       IF(MB.GE.MA) GO TO 64                                             001470
       IF(IZ.LE.0) GO TO 63                                              001480
       N=N+1                                                             001490
       IBPA(N)=MA                                                        001500
       IBPB(N)=MA                                                        001510
       QBF(N)=.5*QBM                                                     001520
       IBZN(N)=IZ                                                        001530
       GO TO 68                                                          001540
    63 WELL(MA)=QB*QBM                                                   001550
       GO TO 80                                                          001560
    64 QBM=.5*QBM                                                        001570
       IF(IZ.LE.0) GO TO 70                                              001580
       DO 66 L=MA,MB,M                                                   001590
       N=N+1                                                             001600
       IBPA(N)=L                                                         001610
       IBPB(N)=L+M                                                       001620
       K=K+1                                                             001630
       TEMP=DX(K)                                                        001640
       IF(M.EQ.ID) TEMP=DY(K)                                            001650
       QBF(N)=QBM*TEMP                                                   001660
    66 IBZN(N)=IZ                                                        001670
    68 QBND(IZ)=QB                                                       001680
```

```
      RK(IZ)=STDER                                                      001690
      GO TO 80                                                          001700
   70 TMP=QB*QBM                                                        001710
      DO 75 L=MA,MB,M                                                   001720
      K=K+1                                                             001730
      TEMP=DX(K)                                                        001740
      IF(M.EQ.ID) TEMP=DY(K)                                            001750
      TEMP=TMP*TEMP                                                     001760
      WELL(L)=WELL(L)+TEMP                                              001770
   75 WELL(L+M)=WELL(L+M)+TEMP                                          001780
   80 CONTINUE                                                          001790
      NQSD=N                                                            001800
C**READ SPECIFIED BOUNDARY HEAD POSITIONS AS -1'S                       001810
   85 CALL ARRAYI(IN,ID,JD,2,0)                                         001820
C**READ DATA AND FORM ARRAYS FOR SPECIFIED HEADS AND PARAMETERS         001830
      IBHZ=0                                                            001840
      IF(NBHZ.LE.0) GO TO 110                                           001850
      WRITE(IOUT,833)                                                   001860
      NBH=0                                                             001870
      DO 108 KK=1,NBHZ                                                  001880
      READ(IIN,834) IZ,NN,M,N,STEHA,STEHB                               001890
      WRITE(IOUT,836) IZ,NN,M,N,STEHA,STEHB                             001900
      DO 95 J=1,NN                                                      001910
       READ(IIN,826) ILOC(J),JLOC(J),V(J)                               001920
   95 WRITE(IOUT,840) ILOC(J),JLOC(J),V(J)                              001930
      IF(IZ.LE.0) GO TO 97                                              001940
      BH(M)=V(1)                                                        001950
      RK(M+NBQZ)=STEHA                                                  001960
      BH(N)=V(NN)                                                       001970
      RK(N+NBQZ)=STEHB                                                  001980
      IZ=IZ+NQSD                                                        001990
      IBPA(IZ)=M+NBQZ                                                   002000
      IBPB(IZ)=N+NBQZ                                                   002010
   97 J=JLOC(1)                                                         002020
      K=ILOC(1)+JPOS(J)                                                 002030
      IF(IN(K).LT.-1) GO TO 100                                         002040
      NBH=NBH+1                                                         002050
      IF(IZ.GT.0) IN(K)=-NBH-1                                          002060
      IBZN(NBH+NQSD)=IZ                                                 002070
      PLA(NBH)=V(1)                                                     002080
      PLB(NBH)=0.                                                       002090
  100 IBHZ=1                                                            002100
      IF(NN.LE.1) GO TO 108                                             002110
      DIST=0.                                                           002120
      DO 102 KNT=2,NN                                                   002130
      J=JLOC(KNT)                                                       002140
      L=ILOC(KNT)+JPOS(J)                                               002150
      IBHZ=1                                                            002160
      NBH=NBH+1                                                         002170
      IF(IZ.GT.0) IN(L)=-NBH-1                                          002180
      IBZN(NBH+NQSD)=IZ                                                 002190
      JM1=JLOC(KNT-1)                                                   002200
      IF(J.EQ.JM1) GO TO 101                                            002210
```

```
      J=MIN0(J,JM1)                                                    002220
      DIST=DIST+DY(J)                                                  002230
      GO TO 102                                                        002240
  101 I=MIN0(ILOC(KNT),ILOC(KNT-1))                                    002250
      DIST=DIST+DX(I)                                                  002260
  102 PLB(NBH)=DIST                                                    002270
      DO 106 KNT=2,NN                                                  002280
      J=JLOC(KNT)                                                      002290
      L=ILOC(KNT)+JPOS(J)                                              002300
      N=-IN(L)-1                                                       002310
      TMP=PLB(N)/DIST                                                  002320
      TMPA=TMP*V(NN)                                                   002330
      TMPB=(1.-TMP)*V(1)                                               002340
      TMPC=TMPA+TMPB                                                   002350
      IF(ABS(V(KNT)).LE.0.) GO TO 104                                  002360
      TMP=V(KNT)/TMPC                                                  002370
      TMPA=TMPA*TMP                                                    002380
      TMPB=TMPB*TMP                                                    002390
      TMPC=V(KNT)                                                      002400
  104 PLA(N)=TMPB                                                      002410
      PLB(N)=TMPA                                                      002420
  106 HC(L)=TMPC                                                       002430
  108 HC(K)=V(1)                                                       002440
      IF(NBHP.LE.0) IBHZ=0                                             002450
C**COMPARE T WITH IZN FOR CONFLICT                                     002460
  110 IER=0                                                            002470
      N=0                                                              002480
      DO 115 J=1,JM                                                    002490
      DO 115 I=1,IM                                                    002500
      N=N+1                                                            002510
      IF(IZN(N).LE.0) GO TO 115                                        002520
      IF(T(N).GT.0.) GO TO 115                                         002530
      IER=1                                                            002540
      WRITE(IOUT,842) I,J                                              002550
  115 CONTINUE                                                         002560
      IF(IER.LT.1) GO TO 120                                           002570
      WRITE(IOUT,844)                                                  002580
      STOP                                                             002590
C**TRANSFER DOMAIN GEOMETRY TO IN(M)                                   002600
  120 N=0                                                              002610
      DO 122 J=1,JM                                                    002620
      DO 122 I=1,IM                                                    002630
      N=N+1                                                            002640
      IF(IZN(N).LE.0) GO TO 122                                        002650
      M=N+J                                                            002660
      IF(IN(M).GE.0) IN(M)=1                                           002670
      IF(IN(M-1).GE.0) IN(M-1)=1                                       002680
      IF(IN(M+ID-1).GE.0) IN(M+ID-1)=1                                 002690
      IF(IN(M+ID).GE.0) IN(M+ID)=1                                     002700
  122 CONTINUE                                                         002710
C**SET UP D4 ORDERING                                                  002720
      CALL ORDER(JPOS,IN,IC)                                           002730
      NVAR=NPAR+NBPAR                                                  002740
```

```
      NVX2=NVAR+NVAR                                                    002750
      NVX3=NVX2+NVAR                                                    002760
C**COMPUTE AND COUNT PRIOR INFORMATION DATA                             002770
      NPRIR=0                                                           002780
      DO 125 I=1,NVAR                                                   002790
      P(I)=1.                                                           002800
      IF(RK(I).LE.0.) GO TO 125                                         002810
      RK(I)=EV/(RK(I)*RK(I))                                            002820
      NPRIR=NPRIR+1                                                     002830
  125 CONTINUE                                                          002840
C** ADJUST DX AND DY                                                    002850
      DO 130 I=1,IM                                                     002860
  130 DX(I)=.5*DX(I)                                                    002870
      DO 135 J=1,JM                                                     002880
  135 DY(J)=.5*DY(J)                                                    002890
C**COMPUTE INITIAL SOLUTION                                             002900
      CALL COEF(DX,DY,T,SL,QRE,WELL,HR,HC,TRANX,TRANY,VLEAK,QDIST,QBND  002910
     1,QBF,PLA,PLB,S,V,IZN,IBZN,IPRM,IBPA,IBPB,IN,IC,NVE)               002920
      CALL D4SOLVE(HC,V,IN,IC,HCA,NHCA,ID,JD,ISO)                       002930
      WRITE(IOUT,846)                                                   002940
      CALL ARRAY(HC,ID,JD,0,1)                                          002950
      IF(ISO.EQ.1) GO TO 640                                            002960
C**COMPUTE INITIAL ERROR VARIANCE                                       002970
      OBS=0.                                                            002980
      YSQ=0.                                                            002990
      DO 160 N=1,NHCA                                                   003000
C  CHECK LOCATION OF THE OBS HEADS, CORRECT WEIGTHING IF OUTSIDE ACTIVE  003010
C  AREA                                                                 003020
      M4=0                                                              003030
      IX=INT(HCA(1,N))                                                  003040
      IY=INT(HCA(2,N))                                                  003050
      I1=(IY-1)*IM+IX                                                   003060
      RESX=HCA(1,N)-IX                                                  003070
      RESY=HCA(2,N)-IY                                                  003080
      I2=(IY-1)*ID+IX                                                   003090
      IF(RESX.EQ.0.0.AND.RESY.EQ.0.0)M4=1                               003100
      IF(M4.GT.0.AND.IN(I2).GT.0)GO TO 163                              003110
      IF(IZN(I1).LE.0)HCA(4,N)=0.0                                      003120
  163 CONTINUE                                                          003130
      IF (HCA(4,N).LE.0.) GO TO 160                                     003140
      OBS=OBS+1.                                                        003150
      TMP=HCA(3,N)-HCA(5,N)                                             003160
      YSQ=YSQ+HCA(4,N)*TMP*TMP                                          003170
  160 CONTINUE                                                          003180
      TEMP=NVAR-NPRIR                                                   003190
      VAR=YSQ/(OBS-TEMP)                                                003200
      NTMP=OBS                                                          003210
      WRITE(IOUT,848) NTMP,NPRIR,YSQ,VAR                                003220
      DO 161 N=1,NHCA                                                   003230
  161 WRITE(IOUT,162)(HCA(I,N),I=1,5)                                   003240
  162 FORMAT(5F10.2)                                                    003250
C**BEGIN ITERATIONS                                                     003260
      INDT=0                                                            003270
```

```
      ER=.01                                                                  003280
      ERP=1000.                                                               003290
      DO 340 KNT=1,NUM                                                        003300
      KOUNT=KNT                                                               003310
C**COMPUTE HC(N)+DELTHC(N)                                                    003320
      CALL COEF(DX,DY,T,SL,QRE,WELL,HR,HC,TRANX,TRANY,VLEAK,QDIST,QBND        003330
     1,QBF,PLA,PLB,S,V,IZN,IBZN,IPRM,IBPA,IBPB,IN,IC,NVE)                     003340
      CALL D4SOLVE(HC,V,IN,IC,HCA,NHCA,ID,JD,ISO)                             003350
C**SOLVE FOR SCALED SENSITIVITIES                                             003360
      DO 260 K=1,NVAR                                                         003370
      DO 170 N=1,NEQ                                                          003380
  170 V(N)=S(K,N)                                                             003390
C**MODIFY R.H.S. UPPER HALF.                                                  003400
      DO 190 J=1,ICR1                                                         003410
      II=IC(1,J)                                                              003420
      DO 180 I=2,II                                                           003430
      LR=IC(I,J)                                                              003440
      V(LR)=V(LR)-AU(I,J)*V(J)                                                003450
  180 CONTINUE                                                                003460
  190 V(J)=V(J)/AU(1,J)                                                       003470
C**MODIFY R.H.S. LOWER HALF.                                                  003480
      JJ=NEQ-ICR                                                              003490
      DO 210 J=1,JJ                                                           003500
      JR=J+ICR1                                                               003510
      LR=JR                                                                   003520
      DO 200 I=2,IB1                                                          003530
      LR=LR+1                                                                 003540
      IF (AL(I,J).NE.0.) V(LR)=V(LR)-AL(I,J)*V(JR)                            003550
  200 CONTINUE                                                                003560
  210 V(JR)=V(JR)/AL(1,J)                                                     003570
C**BACK SOLVE LOWER HALF                                                      003580
      V(NEQ)=V(NEQ)/AL(1,NEQ-ICR1)                                            003590
      S(K,NEQ)=V(NEQ)                                                         003600
      DO 230 J=1,JJ                                                           003610
      KK=NEQ-J                                                                003620
      KL=KK-ICR1                                                              003630
      L=KK                                                                    003640
      DO 220 I=2,IB1                                                          003650
      L=L+1                                                                   003660
      IF (AL(I,KL).NE.0.) V(KK)=V(KK)-AL(I,KL)*V(L)                           003670
  220 CONTINUE                                                                003680
      S(K,KK)=V(KK)                                                           003690
  230 CONTINUE                                                                003700
C**BACK SOLVE UPPER HALF                                                      003710
      DO 250 J=1,ICR1                                                         003720
      KK=ICR-J                                                                003730
      II=IC(1,KK)                                                             003740
      DO 240 I=2,II                                                           003750
      L=IC(I,KK)                                                              003760
      V(KK)=V(KK)-AU(I,KK)*V(L)                                               003770
  240 CONTINUE                                                                003780
      S(K,KK)=V(KK)                                                           003790
  250 CONTINUE                                                                003800
```

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  260 CONTINUE                                                          003810
      IF(IPO.NE.1) GO TO 270                                            003820
      WRITE(IOUT,850)                                                   003830
      N=0                                                               003840
      DO 265 J=1,JD                                                     003850
      DO 265 I=1,ID                                                     003860
      N=N+1                                                             003870
      L=IN(N)                                                           003880
      IF(L.LE.0) GO TO 265                                              003890
      WRITE(IOUT,852) I,J,(S(K,L),K=1,NVAR)                             003900
  265 CONTINUE                                                          003910
C**CALL LEAST SQUARES                                                   003920
  270 CALL LSTSQ(HCA,HC,P,RK,PLA,PLB,S,V,IBZN,IBPA,IBPB,IN,NVE,NHCA)    003930
      IF(INDT.GT.0) GO TO 521                                           003940
      IF(IPO.EQ.1) WRITE(IOUT,854)                                      003950
C**COMPUTE NEW SPECIFIED FLOW PARAMETERS                                003960
      IF(NBQZ.LE.0) GO TO 282                                           003970
      DO 280 K=1,NBQZ                                                   003980
      QBND(K)=(V(K)+1.)*QBND(K)                                         003990
      IF(IPO.EQ.1) WRITE(IOUT,856) K,QBND(K)                            004000
  280 CONTINUE                                                          004010
C**COMPUTE NEW SPECIFIED HEAD PARAMETERS                                004020
  282 IF(NBHP.LE.0) GO TO 290                                           004030
      DO 284 J=1,NBHP                                                   004040
      BH(J)=(V(J+NBQZ)+1.)*BH(J)                                        004050
      IF(IPO.EQ.1) WRITE(IOUT,856) J,BH(J)                              004060
  284 CONTINUE                                                          004070
      DO 286 J=1,NIJ                                                    004080
      N=IN(J)                                                           004090
      IF(N.GE.-1) GO TO 286                                             004100
      N=-N-1                                                            004110
      M=IBZN(N+NQSD)                                                    004120
      K=IBPA(M)                                                         004130
      L=IBPB(M)                                                         004140
      PLA(N)=PLA(N)*(V(K)+1.)                                           004150
      PLB(N)=PLB(N)*(V(L)+1.)                                           004160
      HC(J)=PLA(N)+PLB(N)                                               004170
  286 CONTINUE                                                          004180
C**UPDATE ZONAL PARAMETERS                                              004190
  290 DO 300 K=1,NZNS                                                   004200
      L=IPRM(1,K)                                                       004210
      IF(L.GT.NBPAR) TRANX(K)=TRANX(K)*(V(L)+1.)                        004220
      L=IPRM(2,K)                                                       004230
      IF(L.GT.NBPAR) TRANY(K)=TRANY(K)*(V(L)+1.)                        004240
      L=IPRM(3,K)                                                       004250
      IF(L.GT.NBPAR) VLEAK(K)=VLEAK(K)*(V(L)+1.)                        004260
      L=IPRM(4,K)                                                       004270
      IF(L.GT.NBPAR) QDIST(K)=QDIST(K)*(V(L)+1.)                        004280
      IF(IPO.EQ.1) WRITE(IOUT,814) K,TRANX(K),TRANY(K),VLEAK(K),QDIST(K)004290
  300 CONTINUE                                                          004300
C**COMPUTE NEW HEADS AT GRID POINTS                                     004310
      DO 320 N=1,NIJ                                                    004320
      L=IN(N)                                                           004330
```

```
      IF(L.LE.0) GO TO 320                                              004340
      SUM=0.                                                            004350
      DO 310 K=1,NVAR                                                   004360
  310 SUM=SUM+V(K)*S(K,L)                                               004370
      HC(N)=HC(N)+SUM                                                   004380
  320 CONTINUE                                                          004390
C*MODIFICATION* INTERPOLATE CALCULATED HEADS AT NODES TO                 004400
C                OBSERVATION HEAD LOCATIONS                             004410
      DO 371 N=1,NHCA                                                   004420
      IX=INT(HCA(1,N))                                                  004430
      IY=INT(HCA(2,N))                                                  004440
      I1=(IY-1)*ID+IX                                                   004450
      RESX=HCA(1,N)-IX                                                  004460
      RESY=HCA(2,N)-IY                                                  004470
      WA=HC(I1+1)-HC(I1)                                                004480
      WB=HC(I1+ID)-HC(I1)                                               004490
      WC=HC(I1+ID+1)+HC(I1)-HC(I1+1)-HC(I1+ID)                          004500
      WD=HC(I1)                                                         004510
  371 HCA(5,N)=WA*RESX+WB*RESY+WC*RESX*RESY+WD                          004520
C**CHECK FOR CONVRGENCE                                                 004530
      DO 330 K=1,NVAR                                                   004540
      IF(ABS(V(K)/AP).GT.ER) GO TO 335                                  004550
  330 CONTINUE                                                          004560
      GO TO 350                                                         004570
C**  CALCULATE NEW SCALED PRIOR INFORMATION PARAMETERS                  004580
  335 IND=0                                                             004590
      DO 337 I=1,NVAR                                                   004600
      TEMP=V(I)+1.                                                      004610
      P(I)=P(I)/TEMP                                                    004620
      IF(ABS(P(I)).LT.ERP) GO TO 337                                    004630
      WRITE(IOUT,858) I                                                 004640
      IND=1                                                             004650
  337 RK(I)=RK(I)*TEMP*TEMP                                             004660
      IF(IND.GT.0) GO TO 360                                            004670
  340 CONTINUE                                                          004680
      WRITE(IOUT,860) NUM                                               004690
      GO TO 360                                                         004700
  350 WRITE(IOUT,862) KOUNT                                             004710
C** COMPUTE SUM OF SQUARES AND CORRELATION COEFFICIENT                  004720
  360 SUMA=0.                                                           004730
C*MODIFICATION* BASED ON NON-NODAL HEAD OBSERVATIONS                    004740
      SUMB=0.                                                           004750
      SUMC=0.                                                           004760
      SUMD=0.                                                           004770
      SUM=0.                                                            004780
      DO 370 N=1,NHCA                                                   004790
      IF (HCA(4,N).LE.0.) GO TO 370                                     004800
      TMP=HCA(4,N)**.5                                                  004810
      HCA(4,N)=TMP                                                      004820
      TEMP=TMP*HCA(3,N)                                                 004830
      TMP=TMP*HCA(5,N)                                                  004840
      SUMA=SUMA+TEMP                                                    004850
      SUMB=SUMB+TMP                                                     004860
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```
      SUMC=SUMC+TEMP*TEMP                                                    004870
      SUMD=SUMD+TMP*TMP                                                      004880
      SUM=SUM+TEMP*TMP                                                       004890
  370 CONTINUE                                                               004900
      R=(OBS*SUM-SUMA*SUMB)/((OBS*SUMC-SUMA*SUMA)*(OBS*SUMD-SUMB*SUMB))      004910
     1**.5                                                                   004920
      TEMP=AP*(2.-AP)                                                        004930
      TMPA=2.*AP*RP/TEMP                                                     004940
      SUM=0.                                                                 004950
      DO 380 I=1,NVAR                                                        004960
      TMP=P(I)-1.                                                            004970
  380 SUM=SUM+TEMP*V(I+NVAR)*(V(I+NVX2)-TMPA*V(I+NVX3)*(RPF*P(I)-1.))        004980
     1-RK(I)*TMP*TMP                                                         004990
      YSQ=YSQ-SUM                                                            005000
C**COMPUTE SCALED VARIANCE-COVARIANCE MATRIX, ERROR VARIANCE, AND           005010
C**OPTIMUM BIAS PARAMETER:                                                  005020
C**CORRECT A FOR MARQUARDT PARAMETER                                        005030
      IF (NVAR.EQ.1) GO TO 435                                               005040
      IF(AMP.LE.0) GO TO 386                                                 005050
      DO 384 I=1,NVAR                                                        005060
      A(I,I)=1.+RP                                                           005070
      DO 382 J=1,NVAR                                                        005080
  382 A(J,I)=A(I,J)                                                          005090
  384 CONTINUE                                                               005100
      AMP=-1.                                                                005110
      CALL LSTSQ(HCA,HC,P,RK,PLA,PLB,S,V,IBZN,IBPA,IBPB,IN,NVE,NHCA)         005120
      IF(INDT.GT.0) GO TO 521                                                005130
C**COMPUTE A-INVERSE                                                        005140
  386 A(NVAR,NVAR)=1./A(NVAR,NVAR)                                           005150
      NM1=NVAR-1                                                             005160
      DO 430 K=1,NM1                                                         005170
      KP1=K+1                                                                005180
      DO 400 I=KP1,NVAR                                                      005190
      SUM=0.                                                                 005200
      IM1=I-1                                                                005210
      DO 390 J=K,IM1                                                         005220
  390 SUM=SUM+A(I,J)*A(J,K)                                                  005230
      A(K,I)=-SUM                                                            005240
  400 A(I,K)=-SUM*A(I,I)                                                     005250
      DO 420 J=1,K                                                           005260
      SUM=A(K,J)                                                             005270
      DO 410 I=KP1,NVAR                                                      005280
  410 SUM=SUM+A(I,J)*A(K,I)                                                  005290
      A(K,J)=SUM                                                             005300
  420 A(J,K)=A(K,J)                                                          005310
  430 CONTINUE                                                               005320
      GO TO 440                                                              005330
  435 A(1,1)=1./(1.+RP)                                                      005340
  440 DO 450 J=1,NVAR                                                        005350
      V(J)=0.                                                                005360
      V(J+NVAR)=AP*V(J+NVAR)+V(J+NVX3)                                       005370
      P(J)=V(J+NVX3)*P(J)                                                    005380
  450 A(J,NVAR)=A(NVAR,J)                                                    005390
```

```
C**COMPUTE TR(A-INVERSE**2) AND RPF                                    005400
      TRACE=0.                                                         005410
      RPF=0.                                                           005420
      IF(RP.LE.0..AND.IRPF.LE.0) GO TO 459                             005430
      DO 457 N=1,NVAR                                                  005440
      DO 452 J=1,NVAR                                                  005450
  452 T(J)=A(J,N)                                                      005460
      SUMA=0.                                                          005470
      DO 456 J=N,NVAR                                                  005480
      SUM=0.                                                           005490
      DO 454 I=1,NVAR                                                  005500
  454 SUM=SUM+T(I)*A(I,J)                                              005510
      SL(J)=SUM                                                        005520
      SUMA=SUMA+P(J)*SUM                                               005530
      V(J)=V(J)+P(N)*SUM                                               005540
  456 A(J,N)=A(J,N)-RP*SUM                                             005550
      V(N)=V(N)+SUMA-SL(N)*P(N)                                        005560
  457 TRACE=TRACE+SL(N)                                                005570
      IF(IRPF.LE.0) GO TO 459                                          005580
      SUM=0.                                                           005590
      DO 458 I=1,NVAR                                                  005600
      RPF=RPF+V(I)*V(I+NVAR)                                           005610
  458 SUM=SUM+V(I)*P(I)                                                005620
      RPF=RPF/SUM                                                      005630
C**COMPUTE ERROR VARIANCE AND COV(SCALED PARAMETERS)                   005640
  459 TEMP=NVAR-NPRIR                                                  005650
      VAR=YSQ/(OBS-TEMP+RP*RP*TRACE)                                   005660
      SUM=0.                                                           005670
      DO 462 J=1,NVAR                                                  005680
      TMP=V(J+NVAR)-RPF*P(J)                                           005690
      SUM=SUM+TMP*TMP                                                  005700
      TEMP=V(J+NVX3)                                                   005710
      DO 460 I=J,NVAR                                                  005720
      A(I,J)=VAR*A(I,J)/(V(I+NVX3)*TEMP)                               005730
  460 A(J,I)=A(I,J)                                                    005740
  462 V(J)=A(J,J)**.5                                                  005750
      TEMP=NVAR                                                        005760
      SUM=TEMP*VAR/SUM                                                 005770
C**PRINT ERROR VARIANCE, ESTIMATED SUM OF SQUARED ERRORS, CORRELATION  005780
C**COEFFICIENT, AND OPTIMUM RIDGE PARAMETERS                           005790
      WRITE(IOUT,864) VAR,YSQ,R,SUM,RPF                                005800
C*********PRINT PARAMETERS AND STANDARD ERRORS                        005810
      IF(NBQZ.LE.0) GO TO 466                                          005820
      WRITE(IOUT,866)                                                  005830
      DO 464 J=1,NBQZ                                                  005840
      STDER=QBND(J)*V(J)                                               005850
  464 WRITE(IOUT,856) J,QBND(J),STDER                                  005860
  466 IF(NBHP.LE.0) GO TO 470                                          005870
      WRITE(IOUT,868)                                                  005880
      DO 468 J=1,NBHP                                                  005890
      STDER=BH(J)*V(J+NBQZ)                                            005900
  468 WRITE(IOUT,856) J,BH(J),STDER                                    005910
  470 WRITE(IOUT,870)                                                  005920
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      DO 480 J=1,NZNS                                                   005930
      WRITE(IOUT,814) J,TRANX(J),TRANY(J),VLEAK(J),QDIST(J)             005940
  480 CONTINUE                                                          005950
      WRITE(IOUT,872)                                                   005960
      DO 490 J=1,NZNS                                                   005970
      K=IPRM(1,J)                                                       005980
      STERX=0.                                                          005990
      IF (K.GT.NBPAR) STERX=TRANX(J)*V(K)                               006000
      K=IPRM(2,J)                                                       006010
      STERY=0.                                                          006020
      IF (K.GT.NBPAR) STERY=TRANY(J)*V(K)                               006030
      K=IPRM(3,J)                                                       006040
      STERV=0.                                                          006050
      IF (K.GT.NBPAR) STERV=VLEAK(J)*V(K)                               006060
      K=IPRM(4,J)                                                       006070
      STERQ=0.                                                          006080
      IF (K.GT.NBPAR) STERQ=QDIST(J)*V(K)                               006090
      WRITE(IOUT,814) J,STERX,STERY,STERV,STERQ                         006100
  490 CONTINUE                                                          006110
C*MODIFICATION* MASS BALANCE CALCULATIONS                               006120
      SUMQRE=0.0                                                        006130
      SUMHED=0.0                                                        006140
      SUMLEK=0.0                                                        006150
      SUMQB=0.0                                                         006160
      SUMWELL=0.0                                                       006170
      N=0                                                               006180
      M=0                                                               006190
      MP1=0                                                             006200
C*MODIFICATION* CALCULATE WELL TOTALS                                   006210
      DO 966 I=1,ID                                                     006220
      DO 966 J=1,JD                                                     006230
      MP1=MP1+1                                                         006240
      SUMWELL=SUMWELL+WELL(MP1)                                         006250
  966 CONTINUE                                                          006260
      DO 900 J=1,JM                                                     006270
      DO 901 I=1,IM                                                     006280
      N=N+1                                                             006290
      M=M+1                                                             006300
      IPT=IZN(N)                                                        006310
      IF(IPT.LE.0)GO TO 901                                             006320
      IXT1=0                                                            006330
      IXT2=0                                                            006340
      IXT3=0                                                            006350
      IXT4=0                                                            006360
      IF(NONMB.LE.0)GO TO 948                                           006370
      DO 941 K=1,NONMB                                                  006380
      IF(M.EQ.NLMA(K))IXT1=K                                            006390
      IF(M+1.EQ.NLMA(K))IXT2=K                                          006400
      IF(M+ID.EQ.NLMA(K))IXT3=K                                         006410
  941 IF(M+ID+1.EQ.NLMA(K))IXT4=K                                       006420
  948 CONTINUE                                                          006430
      AREAN=DX(I)*DY(J)                                                 006440
      TP=TRANX(IPT)*T(N)                                                006450
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```
      TQ=TRANY(IPT)*T(N)                                                006460
      SLP=VLEAK(IPT)*SL(N)*AREAN                                        006470
      SUMQ=QRE(N)*QDIST(IPT)*AREAN                                      006480
      IF(IN(M).LE.0)GO TO 930                                           006490
      SUML=SLP*(HR(M)-HC(M))                                            006500
      SUMQRE=SUMQRE+SUMQ                                                006510
      SUMLEK=SUMLEK+SUML                                                006520
      IF(IXT1.GT.0)XLMB(IXT1)=XLMB(IXT1)+SUML                           006530
  930 IF(IN(M+1).LE.0)GO TO 931                                         006540
      SUML=SLP*(HR(M+1)-HC(M+1))                                        006550
      SUMQRE=SUMQRE+SUMQ                                                006560
      SUMLEK=SUMLEK+SUML                                                006570
      IF(IXT2.GT.0)XLMB(IXT2)=XLMB(IXT2)+SUML                           006580
  931 IF(IN(M+ID).LE.0)GO TO 932                                        006590
      SUML=SLP*(HR(M+ID)-HC(M+ID))                                      006600
      SUMQRE=SUMQRE+SUMQ                                                006610
      SUMLEK=SUMLEK+SUML                                                006620
      IF(IXT3.GT.0)XLMB(IXT3)=XLMB(IXT3)+SUML                           006630
  932 IF(IN(M+ID+1).LE.0)GO TO 933                                      006640
      SUML=SLP*(HR(M+ID+1)-HC(M+ID+1))                                  006650
      SUMQRE=SUMQRE+SUMQ                                                006660
      SUMLEK=SUMLEK+SUML                                                006670
      IF(IXT4.GT.0)XLMB(IXT4)=XLMB(IXT4)+SUML                           006680
  933 CONTINUE                                                          006690
C     FIRST DIAGONAL                                                    006700
  910 IF(IN(M).GE.0)GO TO 902                                           006710
      IF(IN(M+1).LE.0)GO TO 903                                         006720
      SUMH=TP*DY(J)*(HC(M)-HC(M+1))/(DX(I)*2)                           006730
      SUMHED=SUMHED+SUMH                                                006740
      IF(IXT1.GT.0)XLMB(IXT1)=XLMB(IXT1)+SUMH                           006750
  903 IF(IN(M+ID).LE.0)GO TO 902                                        006760
      SUMH=TQ*DX(I)*(HC(M)-HC(M+ID))/(DY(J)*2)                          006770
      SUMHED=SUMHED+SUMH                                                006780
      IF(IXT1.GT.0)XLMB(IXT1)=XLMB(IXT1)+SUMH                           006790
  902 IF(IN(M+ID+1).GE.0)GO TO 904                                      006800
      IF(IN(M+1).LE.0)GO TO 905                                         006810
      SUMH=TQ*DX(I)*(HC(M+ID+1)-HC(M+1))/(DY(J)*2)                      006820
      SUMHED=SUMHED+SUMH                                                006830
      IF(IXT4.GT.0)XLMB(IXT4)=XLMB(IXT4)+SUMH                           006840
  905 IF(IN(M+ID).LE.0)GO TO 904                                        006850
      SUMH=TP*DY(J)*(HC(M+ID+1)-HC(M+ID))/(DX(I)*2)                     006860
      SUMHED=SUMHED+SUMH                                                006870
      IF(IXT4.GT.0)XLMB(IXT4)=XLMB(IXT4)+SUMH                           006880
C     SECOND DIAGONAL                                                   006890
  904 IF(IN(M+1).GE.0)GO TO 906                                         006900
      IF(IN(M).LE.0)GO TO 907                                           006910
      SUMH=TP*DY(J)*(HC(M+1)-HC(M))/(DX(I)*2)                           006920
      SUMHED=SUMHED+SUMH                                                006930
      IF(IXT2.GT.0)XLMB(IXT2)=XLMB(IXT2)+SUMH                           006940
  907 IF(IN(M+ID+1).LE.0)GO TO 906                                      006950
      SUMH=TQ*DX(I)*(HC(M+1)-HC(M+1+ID))/(DY(J)*2)                      006960
      SUMHED=SUMHED+SUMH                                                006970
      IF(IXT2.GT.0)XLMB(IXT2)=XLMB(IXT2)+SUMH                           006980
```

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  906 IF(IN(M+ID).GE.0)GO TO 908                                          006990
      IF(IN(M).LE.0)GO TO 909                                             007000
      SUMH=TQ*DX(I)*(HC(M+ID)-HC(M))/(DY(J)*2)                            007010
      SUMHED=SUMHED+SUMH                                                  007020
       IF(IXT3.GT.0)XLMB(IXT3)=XLMB(IXT3)+SUMH                            007030
  909 IF(IN(M+1+ID).LE.0)GO TO 908                                        007040
      SUMH=TP*DY(J)*(HC(M+ID)-HC(M+1+ID))/(DX(I)*2)                       007050
      SUMHED=SUMHED+SUMH                                                  007060
      IF(IXT3.GT.0)XLMB(IXT3)=XLMB(IXT3)+SUMH                             007070
  908 CONTINUE                                                            007080
  901 CONTINUE                                                            007090
      M=M+1                                                               007100
  900 CONTINUE                                                            007110
      IF(NQSD.LE.0)GO TO 944                                              007120
      DO 946 K=1,NQSD                                                     007130
  946 SUMQB=SUMQB+QBND(IBZN(K))*QBF(K)*2                                  007140
  944 CONTINUE                                                            007150
      TOTALS=SUMQRE+SUMHED+SUMLEK+SUMWELL+SUMQB                           007160
      WRITE(IOUT,999)TOTALS,SUMQRE,SUMHED,SUMLEK,SUMWELL,SUMQB            007170
  999 FORMAT(1X,"MASS BALANCE",G10.4,5X,"SUMQRE",G10.4,5X,                007180
     1"SUMHED",G10.4,5X,"SUMLEK",G10.4,5X,"SUMWELL",G10.4,"SUMQB",G10.4,) 007190
      WRITE(IOUT,997)                                                     007200
      IF(NONMB.LE.0)GO TO 947                                             007210
      DO 995 I=1,NONMB                                                    007220
  995 WRITE(IOUT,996)NLMA(I),NLMB(I*2-1),NLMB(I*2),XLMB(I)                007230
     1,HC(NLMA(I)),HR(NLMA(I))                                            007240
  947 CONTINUE                                                            007250
  997 FORMAT(1X,"SEQUENCE NO.",5X,"COLUMN",5X,"ROW",6X,"LEAKAGE OR CONST007260
     1ANT HEAD FLUX",4X,"COMPUTED HEAD",2X,"FIXED HEAD")                  007270
  996 FORMAT(6X,I5,8X,I5,3X,I5,5X,G10.4,12X,G10.4,12X,G10.4               007280
     1,19X,G10.4)                                                         007290
      WRITE(IOUT,961)                                                     007300
      CALL ARRAY(HC,ID,JD,0,1)                                            007310
  961 FORMAT(1H0,1X,15HFINAL SOLUTION:)                                   007320
C*********PRINT SCALED VARIANCE-COVARIANCE MATRIX                        007330
      WRITE(IOUT,874)                                                     007340
      CALL PRTOT(A,NVE,0)                                                 007350
C*********COMPUTE AND PRINT CORRELATION MATRIX FOR PARAMETERS             007360
      DO 510 J=1,NVAR                                                     007370
      TEMP=V(J)                                                           007380
      DO 500 I=J,NVAR                                                     007390
      A(I,J)=A(I,J)/(V(I)*TEMP)                                           007400
  500 A(J,I)=A(I,J)                                                       007410
  510 CONTINUE                                                            007420
      WRITE(IOUT,876)                                                     007430
      CALL PRTOT(A,NVE,0)                                                 007440
C*********COMPUTE AND PRINT RESIDUALS                                     007450
C*MODIFICATION* BASED ON NON-NODAL HEAD OBSERVATIONS                      007460
      WRITE(IOUT,878)                                                     007470
      N=0                                                                 007480
      RESMN=0.0                                                           007490
      RESABS=0.0                                                          007500
      XINTX=1.0                                                           007510
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      YINTY=1.0                                                          007520
      CONIN=100.0                                                        007530
      NCITU=0                                                            007540
      DO 520 N=1,NHCA                                                    007550
      RES=HCA(4,N)*(HCA(5,N)-HCA(3,N))                                   007560
      RESMN=RESMN+RES                                                    007570
      RESABS=RESABS+ABS(RES)                                             007580
      WRITE(IOUT,880) HCA(1,N),HCA(2,N),HCA(5,N),HCA(3,N),RES            007590
      WRITE(4,958)HCA(1,N),HCA(2,N),RES                                  007600
  520 CONTINUE                                                           007610
      TRESM=RESMN/NHCA                                                   007620
      TRESA=RESABS/NHCA                                                  007630
      WRITE(IOUT,943)TRESM,TRESA                                         007640
  943 FORMAT(1X,"MEAN RESIDUAL",F10.2,2X,"ABSOLUTE MEAN RESIDUAL",F10.2) 007650
      NDW=0                                                              007660
  958 FORMAT(3F10.2)                                                     007670
      DO 978 J=1,JD                                                      007680
      DO 978 I=1,ID                                                      007690
      NDW=NDW+1                                                          007700
      IF(IN(NDW).EQ.0)GO TO 978                                          007710
      NCITU=NCITU+1                                                      007720
  978 CONTINUE                                                           007730
      WRITE(5,800)NCITU                                                  007740
      WRITE(5,957)XINTX,YINTY,CONIN                                      007750
      N=0                                                                007760
      DO 956 J=1,JD                                                      007770
      DO 956 I=1,ID                                                      007780
      N=N+1                                                              007790
      IF(IN(N).EQ.0)GO TO 956                                            007800
      XIX=FLOAT(I)                                                       007810
      YIY=FLOAT(J)                                                       007820
      WRITE(5,957)XIX,YIY,HC(N)                                          007830
  956 CONTINUE                                                           007840
  957 FORMAT(2F5.1,F10.2)                                                007850
C**PRINT SCALED SENSITIVITIES FOR EACH NODE                              007860
  521 IF(IPRX.LE.0.AND.KOUNT.LT.NUM) STOP                                007870
      WRITE(IOUT,882)                                                    007880
      DO 530 KK=1,NVAR                                                   007890
      WRITE(IOUT,884) KK                                                 007900
      DO 525 N=1,NIJ                                                     007910
      HC(N)=0.                                                           007920
      L=IN(N)                                                            007930
      IF(L.GT.0) GO TO 523                                               007940
      IF(L.GE.-1) GO TO 525                                              007950
      L=-L-1                                                             007960
      IZ=IBZN(L+NQSD)                                                    007970
      IF(IBPB(IZ).EQ.KK) HC(N)=PLB(L)                                    007980
      IF(IBPA(IZ).EQ.KK) HC(N)=PLA(L)                                    007990
      GO TO 525                                                          008000
  523 HC(N)=S(KK,L)                                                      008010
  525 CONTINUE                                                           008020
  530 CALL ARRAY(HC,ID,JD,0,1)                                           008030
      IF(NVAR.LT.2) STOP                                                 008040
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C**ORTHOGONALIZE SENSITIVITY MATRIX (S):                                008050
C**DEFINE I AND J POINTERS                                              008060
C*MODIFICATION* BASED ON NON-NODAL HEAD OBSERVATIONS                    008070
      N=0                                                               008080
      DO 531 J=1,JD                                                     008090
      DO 531 I=1,ID                                                     008100
      N=N+1                                                             008110
      K=IN(N)                                                           008120
      IF(K.LE.0) GO TO 531                                              008130
      ILOC(K)=I                                                         008140
      JLOC(K)=J                                                         008150
  531 CONTINUE                                                          008160
C**DEFINE DUMMY WEIGHT MATRIX                                           008170
      DO 541 I=1,NIJ                                                    008180
  541 DUM(I)=0.0                                                        008190
      DO 542 I=1,NHCA                                                   008200
      IF(HCA(4,I).LT.1.E-10)GO TO 542                                   008210
      IXI=INT(HCA(1,I)+.5)                                              008220
      JYJ=INT(HCA(2,I)+.5)                                              008230
      NUML=IXI+(JYJ-1)*ID                                               008240
      IF(HCA(4,I).GT.DUM(NUML))DUM(NUML)=HCA(4,I)                       008250
  542 CONTINUE                                                          008260
C**COMPRESS S                                                           008270
      N=0                                                               008280
      DO 533 L=1,NEQ                                                    008290
      J=JLOC(L)                                                         008300
      K=ILOC(L)+JPOS(J)                                                 008310
      IF(DUM(K).LE.1.E-10)GO TO 533                                     008320
      N=N+1                                                             008330
      ILOC(N)=ILOC(L)                                                   008340
      JLOC(N)=JLOC(L)                                                   008350
      DO 532 J=1,NVAR                                                   008360
  532 S(J,N)=S(J,L)*DUM(K)                                              008370
  533 CONTINUE                                                          008380
      NOOB=N                                                            008390
      IF(IBHZ.LE.0) GO TO 536                                           008400
      KK=0                                                              008410
      DO 535 J=1,JD                                                     008420
      DO 535 I=1,ID                                                     008430
      KK=KK+1                                                           008440
      NN=IN(KK)                                                         008450
      IF(NN.GE.-1.OR.DUM(KK).LE.1.E-10)GO TO 535                        008460
      N=N+1                                                             008470
      ILOC(N)=I                                                         008480
      JLOC(N)=J                                                         008490
      DO 534 K=1,NVAR                                                   008500
  534 S(K,N)=0.                                                         008510
      NN=-NN-1                                                          008520
      M=IBZN(NN+NQSD)                                                   008530
      K=IBPA(M)                                                         008540
      L=IBPB(M)                                                         008550
      S(L,N)=PLB(NN)*DUM(KK)                                            008560
      S(K,N)=PLA(NN)*DUM(KK)                                            008570
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  535 CONTINUE                                                          008580
  536 IF(NPRIR.LE.0) GO TO 539                                          008590
      DO 538 I=1,NVAR                                                   008600
      IF(RK(I).LT.1.E-10) GO TO 538                                     008610
      N=N+1                                                             008620
      ILOC(N)=I                                                         008630
      JLOC(N)=0                                                         008640
      DO 537 J=1,NVAR                                                   008650
  537 S(J,N)=0.                                                         008660
      S(I,N)=RK(I)**.5                                                  008670
  538 CONTINUE                                                          008680
C**ORTHOGONALIZE S                                                      008690
  539 NTMP=NOOB+NPRIR                                                   008700
      DO 540 I=1,NTMP                                                   008710
  540 DUM(I)=S(1,I)                                                     008720
      DO 600 N=2,NVAR                                                   008730
      NM1=N-1                                                           008740
      SUM=0.                                                            008750
      DO 550 I=1,NTMP                                                   008760
      SUM=SUM+DUM(I)*DUM(I)                                             008770
      S(NM1,I)=DUM(I)                                                   008780
  550 CONTINUE                                                          008790
      IF(SUM.LT.1.E-20) GO TO 610                                       008800
      V(NM1)=1./SUM                                                     008810
      DO 570 J=1,NM1                                                    008820
      SUM=0.                                                            008830
      DO 560 K=1,NTMP                                                   008840
  560 SUM=SUM+V(J)*S(J,K)*S(N,K)                                        008850
  570 T(J)=SUM                                                          008860
      DO 590 K=1,NTMP                                                   008870
      SUM=0.                                                            008880
      DO 580 I=1,NM1                                                    008890
  580 SUM=SUM+S(I,K)*T(I)                                               008900
  590 DUM(K)=S(N,K)-SUM                                                 008910
  600 CONTINUE                                                          008920
C**PRINT ORTHOGONALIZED S                                               008930
  610 WRITE(IOUT,886)                                                   008940
      K=1                                                               008950
      L=8                                                               008960
      DO 630 M=1,NVAR,8                                                 008970
      IF(L.GT.NVAR) L=NVAR                                              008980
      WRITE(IOUT,888) (I,I=K,L)                                         008990
      DO 620 J=1,NTMP                                                   009000
      S(NVAR,J)=DUM(J)                                                  009010
      WRITE(IOUT,890) ILOC(J),JLOC(J),(S(I,J),I=K,L)                    009020
  620 CONTINUE                                                          009030
      K=K+8                                                             009040
      L=L+8                                                             009050
  630 CONTINUE                                                          009060
      STOP                                                              009070
C**READ, PRINT, AND EXECUTE FOR ALTERNATE SOLUTIONS                     009080
  640 READ(IIN,800) N                                                   009090
      IF(N.LE.0) STOP                                                   009100
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      DO 690 K=1,N                                                          009110
      WRITE(IOUT,892) K                                                     009120
      DO 650 L=1,NZNS                                                       009130
      READ(IIN,812) I,TRANX(I),TRANY(I),VLEAK(I),QDIST(I)                   009140
      WRITE(8,814)I,TRANX(I),TRANY(I),VLEAK(I),QDIST(I)                     009150
  650 WRITE(IOUT,814) I,TRANX(I),TRANY(I),VLEAK(I),QDIST(I)                 009160
      IF(NBQZ.LE.0) GO TO 665                                               009170
      DO 660 L=1,NBQZ                                                       009180
  660 READ(IIN,812) I,QBND(I)                                               009190
      WRITE(IOUT,894)                                                       009200
      CALL PRTOT(QBND,NBQZ,1)                                               009210
  665 IF(NBHP.LE.0) GO TO 685                                               009220
      DO 670 L=1,NBHP                                                       009230
  670 READ(IIN,812) I,BH(I)                                                 009240
      WRITE(IOUT,896)                                                       009250
      CALL PRTOT(BH,NBHP,1)                                                 009260
      DO 680 KK=1,NIJ                                                       009270
      NN=IN(KK)                                                             009280
      IF(NN.GE.-1) GO TO 680                                                009290
      NN=-NN-1                                                              009300
      M=IBZN(NN+NQSD)                                                       009310
      L=IBPA(M)                                                             009320
      TMPA=BH(L)*PLA(NN)                                                    009330
      L=IBPB(M)                                                             009340
      TMPB=BH(L)*PLB(NN)                                                    009350
      HC(KK)=TMPA+TMPB                                                      009360
  680 CONTINUE                                                              009370
  685 CALL COEF(DX,DY,T,SL,QRE,WELL,HR,HC,TRANX,TRANY,VLEAK,QDIST,QBND      009380
     1,QBF,PLA,PLB,S,V,IZN,IBZN,IPRM,IBPA,IBPB,IN,IC,NVE)                   009390
      CALL D4SOLVE(HC,V,IN,IC,HCA,NHCA,ID,JD,ISO)                           009400
      WRITE(IOUT,898) K                                                     009410
  690 CONTINUE                                                              009420
      STOP                                                                  009430
C                                                                           009440
  800 FORMAT (16I5)                                                         009450
  801 FORMAT (20A4)                                                         009460
  802 FORMAT(25H0NUMBER OF COLUMNS (ID) =,I5                                009470
     $/22H NUMBER OF ROWS (JD) =,I5                                         009480
     $/39H NUMBER OF EQUIPARAMETER ZONES (NZNS) =,I5                        009490
     $/43H NUMBER OF POINT SOURCES OR SINKS (NWELS) =,I5                    009500
     $/42H NUMBER OF SPECIFIED FLOW ZONES (NQBND) = ,I5                     009510
     $/50H NUMBER OF SPECIFIED FLOW PARAMETER ZONES (NBQZ) =,I5             009520
     $/40H NUMBER OF SPECIFIED HEAD ZONES (NBHZ) =,I5                       009530
     $/45H NUMBER OF SPECIFIED HEAD PARAMETERS (NBHP) =,I5                  009540
     $/44H NUMBER OF REGRESSION PARAMETERS OTHER THAN                       009550
     $/42H SPECIFIED HEAD OR SPECIFIED FLOW (NPAR) =,I5                     009560
     $/37H MAXIMUM NUMBER OF ITERATIONS (NUM) =,I5                          009570
     $/56H SENSITIVITY PRINT AND ORTHOGONALIZATION OPTION (IPRX) =,I5       009580
     $/51H OPTION TO ESTIMATE OPTIMUM BIAS PARAMETER (IRPF) =,I5            009590
     $/35H ADDITIONAL PRINTOUT OPTION (IPO) =,I5                            009600
     $/29H SOLUTION ONLY OPTION (ISO) =,I5)                                 009610
  803 FORMAT (1H ,20A4)                                                     009620
  804 FORMAT (1H1)                                                          009630
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806 FORMAT (46H ACCELERATION PARAMETER FOR REGRESSION (AP) = ,G11.4    009640
   $/44H MARQUARDT PARAMETER FOR REGRESSION (AMP) = ,G11.4             009650
   $/39H RIDGE PARAMETER FOR REGRESSION (RP) = ,G11.4                  009660
   $/39H BIAS PARAMETER FOR REGRESSION (RPF) = ,G11.4                  009670
   $/33H ESTIMATED ERROR VARIANCE (EV) = ,G11.4)                       009680
810 FORMAT (1H0,15X,26HINITIAL PARAMETERS BY ZONE/6H  ZONE,4X,5HTRANX 009690
   1,8X,5HTRANY,8X,5HVLEAK,8X,5HQDIST)                                009700
812 FORMAT (I5,4F10.0)                                                 009710
814 FORMAT (1H ,I4,4(2X,E11.4))                                        009720
816 FORMAT (1H0,15X,17HPARAMETER NUMBERS/1H ,5X,4HZONE,4X,5HTRANX,3X   009730
   1,5HTRANY,3X,5HVLEAK,3X,5HQDIST)                                    009740
818 FORMAT (1H ,8I8)                                                   009750
820 FORMAT (8F10.0)                                                    009760
822 FORMAT (1H0,16X,40HCOEFFICIENTS OF VARIATION FOR PARAMETERS        009770
   1/1H ,3(2X,6HPARAM.,7X,5HCOEF.,4X)/1H ,3(4X,3HNO.,9X,4HVAR.,4X))   009780
824 FORMAT (1H0,4X,25HPOINT SOURCE OR SINK DATA/1H ,7X,1HI,7X,1HJ      009790
   1,6X,4HRATE)                                                        009800
826 FORMAT (2I5,F10.0)                                                 009810
828 FORMAT (1H ,2I8,2X,E11.4)                                          009820
830 FORMAT (1H0,22X,27HINITIAL SPECIFIED FLOW DATA/1H ,6X,9HNODE NO.S  009830
   1,7X,4HZONE,6X,4HFLOW,8X,5HCOEF./1H ,19H  IA   JA   IB   JB,4X     009840
   2,3HNO.,3X,9HPARAMETER,7X,4HVAR.,6X,10HMULTIPLIER)                  009850
831 FORMAT (1H ,4(1X,I3,1X),2X,I3,1X,3(2X,E11.4))                      009860
832 FORMAT (5I5,3F10.0)                                                009870
833 FORMAT (1H0,17X,27HINITIAL SPECIFIED HEAD DATA)                    009880
834 FORMAT(4I5,2F10.0)                                                 009890
836 FORMAT (1H0,22H  NO. OF NODES IN ZONE,I4,3H = ,I3/1H ,15H  NO. PAR009900
   1. A = ,I3,17X,13HNO. PAR. B = ,I3/1H ,22H  COEF. VAR. PAR. A =    009910
   2,E11.4,22H  COEF. PAR. PAR. B = ,E11.4/1H ,20X,22HINITIAL VALUES 0009920
   3F HEAD/1H ,21X,1HI,5X,1HJ,7X,4HHEAD)                               009930
840 FORMAT (1H ,19X,2(I3,3X),E11.4)                                    009940
842 FORMAT(9H0AT CELL ,2I5,15H, IZN>0 AND T=0)                         009950
844 FORMAT(54H0PROGRAM ABORTED BECAUSE OF CONFLICT BETWEEN IZN AND T)  009960
846 FORMAT (1H0,1X,17HINITIAL SOLUTION:)                               009970
848 FORMAT (23H0NO. OF OBSERVATIONS = ,I4/46H NO. OF PARAMETERS HAVING009980
   1 PRIOR INFORMATION = ,I4//56H ESTIMATED SUM OF SQUARED ERRORS FOR  009990
   2INITIAL SOLUTION = ,E12.5/39H ERROR VARIANCE FOR INITIAL SOLUTION  010000
   3= ,E12.5)                                                          010010
850 FORMAT(1H0,5X,58HNODAL LOCATION AND SCALED SENSITIVITIES FOR EACH  010020
   1PARAMETER)                                                         010030
852 FORMAT(1H ,2(1X,I4),7(1X,G11.5)/1H ,(10X,7(1X,G11.5)))             010040
854 FORMAT(19H0UPDATED PARAMETERS)                                     010050
856 FORMAT (1H ,1X,I4,3X,G11.5,4X,G11.5)                               010060
858 FORMAT (11H0PARAMETER ,I3,17H EFFECTIVELY ZERO)                    010070
860 FORMAT (//32H0SOLUTION FAILED TO CONVERGE IN ,I3,11H ITERATIONS)   010080
862 FORMAT (//23H0SOLUTION CONVERGED IN ,I3,11H ITERATIONS)            010090
864 FORMAT (18H0ERROR VARIANCE = ,E12.5/35H ESTIMATED SUM OF SQUARED E010100
   1RRORS = ,E12.5/27H CORRELATION COEFFICIENT = ,F6.4/27H OPTIMUM RID010110
   2GE PARAMETER = ,E12.5/26H OPTIMUM BIAS PARAMETER = ,E12.5)         010120
866 FORMAT(1H0,1X,35HESTIMATED SPECIFIED FLOW PARAMETERS               010130
   1/7H   ZONE,5X,4HQBND,9X,8HSTD. ER.)                               010140
868 FORMAT (1H0,5X,25HESTIMATED SPECIFIED HEADS/1H ,6H  PAR./1H ,3X    010150
   1,3HNO.,5X,4HHEAD,9X,8HSTD. ER.)                                    010160
```

```
870 FORMAT (1H0,14X,28HESTIMATED PARAMETERS BY ZONE/6H  ZONE,4X          010170
   1,5HTRANX,8X,5HTRANY,8X,5HVLEAK,8X,5HQDIST)                          010180
872 FORMAT (1H0,13X,33HESTIMATED STANDARD ERRORS BY ZONE/1H ,8X          010190
   1,8HSTD. ER.,5X,8HSTD. ER.,5X,8HSTD. ER.,5X,8HSTD. ER./6H  ZONE,4X  010200
   2,5HTRANX,8X,5HTRANY,8X,5HVLEAK,8X,5HQDIST)                          010210
874 FORMAT (34H0SCALED VARIANCE-COVARIANCE MATRIX)                      010220
876 FORMAT (34H0CORRELATION MATRIX FOR PARAMETERS)                      010230
878 FORMAT (1H0,21X,18HTABLE OF RESIDUALS/1H ,6X,1HI,5X,1HJ,4X          010240
   1,9HPREDICTED,10X,6HACTUAL,12X,8HWEIGHTED/1H ,17X,5HVALUE,12X       010250
   2,5HVALUE,13X,8HRESIDUAL)                                            010260
880 FORMAT (1H ,1X,2(1X,F5.2),3(4X,G13.6))                              010270
882 FORMAT (26H0SCALED SENSITIVITY ARRAYS)                              010280
884 FORMAT(18H0PARAMETER NUMBER ,I5)                                    010290
886 FORMAT(1H0,5X,33HORTHOGONALIZED SENSITIVITY MATRIX                  010300
   1/1H ,45H NODAL LOCATION AND VALUES FOR EACH PARAMETER)              010310
888 FORMAT (1H ,14X,15HPARAMETER NOS.:/1H ,4X,1HI,4X,1HJ,5X,8(I3,9X))  010320
890 FORMAT (1H ,2(1X,I4),8(1X,G11.5))                                   010330
892 FORMAT (1H0,7X,39HPARAMETERS FOR ADDITIONAL SOLUTION NO. ,I3        010340
   1/6H  ZONE,4X,5HTRANX,8X,5HTRANY,8X,5HVLEAK,8X,5HQDIST)              010350
894 FORMAT (1H0,27X,19HSPECIFIED FLOW DATA/1H ,3X,3(4HFLO#,5X           010360
   1,9HSPECIFIED,6X)/1H ,3X,3(4HZONE,8X,4HFLO#,8X))                    010370
896 FORMAT (1H0,9X,52HSPECIFIED HEAD PARAMETERS, FRACTIONAL CHANGE IN   010380
   1HEAD/1H ,3(8H  PARAM.,4X,9HSPECIFIED,3X)/1H ,3(4X,3HNO.,8X,4HHEAD  010390
   2,5X))                                                               010400
898 FORMAT(13H0SOLUTION NO.,I5)                                         010410
    END                                                                 010420
```

```
      SUBROUTINE ARRAY(A,IND,JND,N,IT)                                  010430
C**IF IT=0, SUBROUTINE FOR LOADING 1 AND 2 DIMENSIONAL ARRAYS           010440
C**IF IT=1, SUBROUTINE FOR PRINTING 2 DIMENSIONAL ARRAYS                010450
      DIMENSION A(IND,JND),NME(8)                                       010460
      COMMON/TNME/IIN,IOUT                                              010470
      DATA NME/4HDX  ,4HDY  ,4HHO  ,4HW   ,4HT   ,4HSL  ,4HHR  ,4HQRE / 010480
      IF(IT.EQ.1) GO TO 55                                              010490
      DO 5 J=1,JND                                                      010500
      DO 5 I=1,IND                                                      010510
    5 A(I,J)=0.                                                         010520
      WRITE(IOUT,105)                                                   010530
      READ(IIN,70) NOZN,IPRN                                            010540
      DO 50 K=1,NOZN                                                    010550
      READ(IIN,70) IB,IE,JB,JE,FACT,IVAR                               010560
      WRITE(IOUT,80) K,IB,IE,JB,JE,NME(N),FACT                          010570
      IF (IVAR.EQ.1) GO TO 20                                           010580
      DO 10 J=JB,JE                                                     010590
      DO 10 I=IB,IE                                                     010600
   10 A(I,J)=FACT                                                       010610
      GO TO 50                                                          010620
   20 DO 40 J=JB,JE                                                     010630
      READ(IIN,90) (A(I,J),I=IB,IE)                                     010640
      DO 40 I=IB,IE                                                     010650
   40 A(I,J)=A(I,J)*FACT                                                010660
   50 CONTINUE                                                          010670
      IF (IPRN.EQ.1) RETURN                                             010680
      WRITE(IOUT,100) NME(N)                                            010690
   55 DO 60 K=1,IND,10                                                  010700
      I10=K+9                                                           010710
      IF(I10.GT.IND) I10=IND                                            010720
      WRITE(IOUT,110) (I,I=K,I10)                                       010730
      WRITE(IOUT,105)                                                   010740
      DO 60 J=1,JND                                                     010750
      JR=JND-J+1                                                        010760
   60 WRITE(IOUT,120) JR,(A(I,JR),I=K,I10)                              010770
      RETURN                                                            010780
C                                                                       010790
   70 FORMAT (4I5,F10.0,3I5)                                            010800
   80 FORMAT (1H ,I3,2X,5HIB = ,I5,2X,5HIE = ,I5,2X,5HJB = ,I5,2X       010810
     1,5HJE = ,I5,2X,A4,2H = ,G12.5)                                    010820
   90 FORMAT (8F10.0)                                                   010830
  100 FORMAT (1H0,2X,A4,7H ARRAY:)                                      010840
  105 FORMAT (1H )                                                      010850
  110 FORMAT (1H0,10X,10(I3,9X))                                        010860
  120 FORMAT (1H ,1X,I3,1X,10(1X,G11.5))                                010870
      END                                                               010880
```

```
      SUBROUTINE ARRAYI(INT,IND,JND,N,IT)                               010890
C**IF IT=0, SUBROUTINE FOR LOADING 1 AND 2 DIMENSIONAL INTEGER ARRAYS   010900
C**IF IT=1, SUBROUTINE FOR PRINTING 2 DIMENSIONAL INTEGER ARRAYS        010910
      DIMENSION INT(IND,JND),NME(2)                                     010920
      COMMON/TNME/IIN,IOUT                                              010930
      DATA NME/4HIZN ,4HIBZN/                                           010940
      IF(IT.EQ.1) GO TO 45                                              010950
      DO 5 J=1,JND                                                      010960
      DO 5 I=1,IND                                                      010970
    5 INT(I,J)=0                                                        010980
      WRITE(IOUT,100)                                                   010990
      READ(IIN,60) NOZN,IPRN                                            011000
      DO 40 K=1,NOZN                                                    011010
      READ(IIN,60) IB,IE,JB,JE,IFACT,IVAR                               011020
      WRITE(IOUT,70) K,IB,IE,JB,JE,NME(N),IFACT                         011030
      IF(IVAR.EQ.1) GO TO 20                                            011040
      DO 10 J=JB,JE                                                     011050
      DO 10 I=IB,IE                                                     011060
   10 INT(I,J)=IFACT                                                    011070
      GO TO 40                                                          011080
   20 DO 30 J=JB,JE                                                     011090
      READ(IIN,60) (INT(I,J),I=IB,IE)                                   011100
   30 CONTINUE                                                          011110
   40 CONTINUE                                                          011120
      IF(IPRN.EQ.1) RETURN                                              011130
      WRITE(IOUT,80) NME(N)                                             011140
   45 DO 50 K=1,IND,30                                                  011150
      I30=K+29                                                          011160
      IF(I30.GT.IND) I30=IND                                            011170
      WRITE(IOUT,90) (I,I=K,I30)                                        011180
      WRITE(IOUT,100)                                                   011190
      DO 50 J=1,JND                                                     011200
      JR=JND-J+1                                                        011210
   50 WRITE(IOUT,110) JR,(INT(I,JR),I=K,I30)                            011220
      RETURN                                                            011230
C                                                                       011240
   60 FORMAT (16I5)                                                     011250
   70 FORMAT (1H ,I3,2X,5HIB = ,I5,2X,5HIE = ,I5,2X,5HJB = ,I5,2X       011260
     1,5HJE = ,I5,2X,A4,2H = ,I5)                                       011270
   80 FORMAT (1H0,2X,A4,7H ARRAY:)                                      011280
   90 FORMAT (1H0,4X,30(1X,I3))                                         011290
  100 FORMAT (1H )                                                      011300
  110 FORMAT (1H ,31(1X,I3))                                            011310
      END                                                               011320
```

```
      SUBROUTINE ORDER(JPOS,IN,IC)                                      011330
      DIMENSION JPOS(1),IN(1),IC(5,1)                                   011340
      COMMON/INT/NIJ,NEQ,ICR,ICR1,IB1,LH1,ID,JD                         011350
      COMMON/TNME/IIN,IOUT                                              011360
C*****COMPUTE EQUATION NUMBERS FOR D4 ORDERING:                         011370
      NXP=ID+JD-1                                                       011380
      K=0                                                               011390
C*****ORDER--LEFT TO RIGHT, BOTTOM TO TOP                               011400
      DO 20 I=1,NXP,2                                                   011410
      DO 20 J=1,JD                                                      011420
      IK=I-J+1                                                          011430
      IF(IK.LT.1.OR.IK.GT.ID) GO TO 20                                  011440
      N=IK+JPOS(J)                                                      011450
      IF(IN(N).LE.0) GO TO 20                                           011460
      K=K+1                                                             011470
      IN(N)=K                                                           011480
   20 CONTINUE                                                          011490
      ICR=K+1                                                           011500
      DO 30 I=2,NXP,2                                                   011510
      DO 30 J=1,JD                                                      011520
      IK=I-J+1                                                          011530
      IF(IK.LT.1.OR.IK.GT.ID) GO TO 30                                  011540
      N=IK+JPOS(J)                                                      011550
      IF(IN(N).LE.0) GO TO 30                                           011560
      K=K+1                                                             011570
      IN(N)=K                                                           011580
   30 CONTINUE                                                          011590
C*****COMPUTE BANDWIDTH AND DETERMINE CONNECTING EQUATION NUMBERS:      011600
      MNO=9999                                                          011610
      MXO=0                                                             011620
      N=0                                                               011630
      DO 80 J=1,JD                                                      011640
      DO 80 I=1,ID                                                      011650
      N=N+1                                                             011660
      JR=IN(N)                                                          011670
      IF (JR.LE.0.OR.JR.GE.ICR) GO TO 80                                011680
      IU=1                                                              011690
C**   BELOW                                                           011700
      IF ((J-1).LT.1) GO TO 40                                          011710
      IF (IN(N-ID).LE.0) GO TO 40                                       011720
      IU=IU+1                                                           011730
      IC(IU,JR)=IN(N-ID)                                                011740
      MM=IN(N-ID)-JR                                                    011750
      MXO=MAXO(MM,MXO)                                                  011760
      MNO=MINO(MM,MNO)                                                  011770
C**   LEFT                                                            011780
   40 IF ((I-1).LT.1) GO TO 50                                          011790
      IF (IN(N-1).LE.0) GO TO 50                                        011800
      IU=IU+1                                                           011810
      IC(IU,JR)=IN(N-1)                                                 011820
      MM=IN(N-1)-JR                                                     011830
      MNO=MINO(MM,MNO)                                                  011840
      MXO=MAXO(MM,MXO)                                                  011850
```

```
C**  RIGHT                                                              011860
   50 IF ((I+1).GT.ID) GO TO 60                                         011870
      IF (IN(N+1).LE.0) GO TO 60                                        011880
      IU=IU+1                                                           011890
      IC(IU,JR)=IN(N+1)                                                 011900
      MM=IN(N+1)-JR                                                     011910
      MXO=MAXO(MM,MXO)                                                  011920
      MNO=MINO(MM,MNO)                                                  011930
C**  ABOVE                                                             011940
   60 IF ((J+1).GT.JD) GO TO 70                                         011950
      IF (IN(N+ID).LE.0) GO TO 70                                       011960
      IU=IU+1                                                           011970
      IC(IU,JR)=IN(N+ID)                                                011980
      MM=IN(N+ID)-JR                                                    011990
      MXO=MAXO(MM,MXO)                                                  012000
      MNO=MINO(MM,MNO)                                                  012010
   70 IC(1,JR)=IU                                                       012020
   80 CONTINUE                                                          012030
      NEQ=K                                                             012040
      ICR1=ICR-1                                                        012050
      IB1=MXO-MNO+1                                                     012060
      LH1=NEQ-ICR1                                                      012070
      WRITE(IOUT,90)                                                    012080
      WRITE(IOUT,100) ICR1,IB1,LH1,ICR1,NEQ                             012090
      RETURN                                                            012100
C                                                                       012110
   90 FORMAT (51H0SOLUTION BY LDU FACTORIZATION ASSUMING D4 ORDERING)    012120
  100 FORMAT (82H ****WARNING*****MINIMUM DIMENSIONS FOR ARRAYS USED BY 012130
     1THIS METHOD ARE AS FOLLOWS:/1H ,4H AU:,8H    5 BY,I5/1H ,4H AL:   012140
     2,I5,3H BY,I5/1H ,4H IC:,8H    5 BY,I5/1H ,4H  B:,I5)             012150
      END                                                               012160
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      SUBROUTINE COEF(DX,DY,T,SL,QRE,WELL,HR,HC,TRANX,TRANY,VLEAK,QDIST 012170
     1,QBND,QBF,PLA,PLB,S,B,IZN,IBZN,IPRM,IBPA,IBPB,IN,IC,NVE)          012180
      DIMENSION DX(1),DY(1),T(1),SL(1),QRE(1),WELL(1),HR(1),HC(1)       012190
     1,TRANX(1),TRANY(1),VLEAK(1),QDIST(1),QBND(1),QBF(1),PLA(1),PLB(1) 012200
     1,S(NVE,1),B(1)                                                    012210
      DIMENSION IZN(1),IBZN(1),IPRM(4,NVE),IBPA(1),IBPB(1),IN(1)        012220
     1,IC(5,1)                                                          012230
      DIMENSION AU(5,550),AL(30,500)                                    012240
      COMMON/INT/NIJ,NEQ,ICR,ICR1,IB1,LH1,ID,JD,IM,JM,NVAR,NQSD,NBPAR   012250
      COMMON/FLT/AU,AL                                                  012260
C**INITIALIZE ARRAYS                                                    012270
      DO 10 J=1,ICR1                                                    012280
      DO 10 I=1,5                                                       012290
   10 AU(I,J)=0.                                                        012300
      DO 20 J=1,LH1                                                     012310
      DO 20 I=1,IB1                                                     012320
   20 AL(I,J)=0.                                                        012330
      DO 40 I=1,NIJ                                                     012340
      N=IN(I)                                                           012350
      IF(N.LE.0) GO TO 40                                               012360
      DO 30 K=1,NVAR                                                    012370
   30 S(K,N)=0.                                                         012380
      B(N)=WELL(I)                                                      012390
   40 CONTINUE                                                          012400
C**CALCULATE -DF/DA*A AND B FOR SPECIFIED FLOW PARAMETERS               012410
      IF(NQSD.LE.0) GO TO 52                                            012420
      DO 50 I=1,NQSD                                                    012430
      IZ=IBZN(I)                                                        012440
      TMP=QBND(IZ)*QBF(I)                                               012450
      INA=IBPA(I)                                                       012460
      L=IN(INA)                                                         012470
      IF(L.LE.0) GO TO 44                                               012480
      S(IZ,L)=S(IZ,L)+TMP                                               012490
      B(L)=B(L)+TMP                                                     012500
   44 INB=IBPB(I)                                                       012510
      L=IN(INB)                                                         012520
      IF(L.LE.0) GO TO 50                                               012530
      S(IZ,L)=S(IZ,L)+TMP                                               012540
      B(L)=B(L)+TMP                                                     012550
   50 CONTINUE                                                          012560
C**BEGIN MAIN LOOP                                                      012570
   52 N=0                                                               012580
      DO 150 J=1,JM                                                     012590
      DYN=DY(J)                                                         012600
      DO 150 I=1,IM                                                     012610
      N=N+1                                                             012620
      M=IZN(N)                                                          012630
      IF(M.LE.0) GO TO 150                                              012640
      NB=N+J                                                            012650
      NA=NB-1                                                           012660
      NC=NB+ID                                                          012670
      ND=NA+ID                                                          012680
      INA=IN(NA)                                                        012690
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```
      INB=IN(NB)                                                        012700
      INC=IN(NC)                                                        012710
      IND=IN(ND)                                                        012720
      TX=TRANX(M)*T(N)                                                  012730
      TY=TRANY(M)*T(N)                                                  012740
      DXN=DX(I)                                                         012750
      CX=TX*DYN/(DXN+DXN)                                               012760
      CY=TY*DXN/(DYN+DYN)                                               012770
      AREA=DXN*DYN                                                      012780
      VL=VLEAK(M)*SL(N)*AREA                                            012790
      QRT=QDIST(M)*QRE(N)*AREA                                          012800
      E=CX+CY+VL                                                        012810
C**CALCULATE AU, AL, B, AND -DF/DA*A FOR TRANSMISSIVITIES, LEAKANCES    012820
C**AND SPECIFIED FLOWS                                                  012830
      L1=IPRM(1,M)                                                      012840
      L2=IPRM(2,M)                                                      012850
      L3=IPRM(3,M)                                                      012860
      L4=IPRM(4,M)                                                      012870
      K=-INA-1                                                          012880
      IF(K) 60,75,53                                                    012890
   53 IZ=IBZN(K+NQSD)                                                   012900
      I1=IBPA(IZ)                                                       012910
      I2=IBPB(IZ)                                                       012920
      IF(INB.LE.0) GO TO 55                                             012930
      S(I1,INB)=S(I1,INB)+CX*PLA(K)                                     012940
      S(I2,INB)=S(I2,INB)+CX*PLB(K)                                     012950
   55 IF(IND.LE.0) GO TO 75                                             012960
      S(I1,IND)=S(I1,IND)+CY*PLA(K)                                     012970
      S(I2,IND)=S(I2,IND)+CY*PLB(K)                                     012980
      GO TO 75                                                          012990
   60 CXT=CX*(HC(NB)-HC(NA))                                            013000
      CYT=CY*(HC(ND)-HC(NA))                                            013010
      VLT=VL*(HR(NA)-HC(NA))                                            013020
      IF(L1.GT.NBPAR) S(L1,INA)=S(L1,INA)+CXT                           013030
      IF(L2.GT.NBPAR) S(L2,INA)=S(L2,INA)+CYT                           013040
      IF(L3.GT.NBPAR) S(L3,INA)=S(L3,INA)+VLT                           013050
      IF(L4.GT.NBPAR) S(L4,INA)=S(L4,INA)+QRT                           013060
      IF(INA.GE.ICR) GO TO 65                                           013070
      AU(1,INA)=AU(1,INA)+E                                             013080
      AU(4,INA)=AU(4,INA)-CX                                            013090
      AU(5,INA)=AU(5,INA)-CY                                            013100
      GO TO 70                                                          013110
   65 AL(1,INA-ICR1)=AL(1,INA-ICR1)+E                                   013120
   70 B(INA)=B(INA)+QRT+VLT+CXT+CYT                                     013130
   75 K=-INB-1                                                          013140
      IF(K) 85,100,77                                                   013150
   77 IZ=IBZN(K+NQSD)                                                   013160
      I1=IBPA(IZ)                                                       013170
      I2=IBPB(IZ)                                                       013180
      IF(INA.LE.0) GO TO 80                                             013190
      S(I1,INA)=S(I1,INA)+CX*PLA(K)                                     013200
      S(I2,INA)=S(I2,INA)+CX*PLB(K)                                     013210
   80 IF(INC.LE.0) GO TO 100                                            013220
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```
      S(I1,INC)=S(I1,INC)+CY*PLA(K)                                    013230
      S(I2,INC)=S(I2,INC)+CY*PLB(K)                                    013240
      GO TO 100                                                        013250
   85 CXT=CX*(HC(NA)-HC(NB))                                           013260
      CYT=CY*(HC(NC)-HC(NB))                                           013270
      VLT=VL*(HR(NB)-HC(NB))                                           013280
      IF(L1.GT.NBPAR) S(L1,INB)=S(L1,INB)+CXT                          013290
      IF(L2.GT.NBPAR) S(L2,INB)=S(L2,INB)+CYT                          013300
      IF(L3.GT.NBPAR) S(L3,INB)=S(L3,INB)+VLT                          013310
      IF(L4.GT.NBPAR) S(L4,INB)=S(L4,INB)+QRT                          013320
      IF(INB.GE.ICR) GO TO 90                                          013330
      AU(1,INB)=AU(1,INB)+E                                            013340
      AU(3,INB)=AU(3,INB)-CX                                           013350
      AU(5,INB)=AU(5,INB)-CY                                           013360
      GO TO 95                                                         013370
   90 AL(1,INB-ICR1)=AL(1,INB-ICR1)+E                                  013380
   95 B(INB)=B(INB)+QRT+VLT+CXT+CYT                                    013390
  100 K=-INC-1                                                         013400
      IF(K) 110,125,102                                                013410
  102 IZ=IBZN(K+NQSD)                                                  013420
      I1=IBPA(IZ)                                                      013430
      I2=IBPB(IZ)                                                      013440
      IF(IND.LE.0) GO TO 105                                           013450
      S(I1,IND)=S(I1,IND)+CX*PLA(K)                                    013460
      S(I2,IND)=S(I2,IND)+CX*PLB(K)                                    013470
  105 IF(INB.LE.0) GO TO 125                                           013480
      S(I1,INB)=S(I1,INB)+CY*PLA(K)                                    013490
      S(I2,INB)=S(I2,INB)+CY*PLB(K)                                    013500
      GO TO 125                                                        013510
  110 CXT=CX*(HC(ND)-HC(NC))                                           013520
      CYT=CY*(HC(NB)-HC(NC))                                           013530
      VLT=VL*(HR(NC)-HC(NC))                                           013540
      IF(L1.GT.NBPAR) S(L1,INC)=S(L1,INC)+CXT                          013550
      IF(L2.GT.NBPAR) S(L2,INC)=S(L2,INC)+CYT                          013560
      IF(L3.GT.NBPAR) S(L3,INC)=S(L3,INC)+VLT                          013570
      IF(L4.GT.NBPAR) S(L4,INC)=S(L4,INC)+QRT                          013580
      IF(INC.GE.ICR) GO TO 115                                         013590
      AU(1,INC)=AU(1,INC)+E                                            013600
      AU(2,INC)=AU(2,INC)-CY                                           013610
      AU(3,INC)=AU(3,INC)-CX                                           013620
      GO TO 120                                                        013630
  115 AL(1,INC-ICR1)=AL(1,INC-ICR1)+E                                  013640
  120 B(INC)=B(INC)+QRT+VLT+CXT+CYT                                    013650
  125 K=-IND-1                                                         013660
      IF(K) 135,150,127                                                013670
  127 IZ=IBZN(K+NQSD)                                                  013680
      I1=IBPA(IZ)                                                      013690
      I2=IBPB(IZ)                                                      013700
      IF(INC.LE.0) GO TO 130                                           013710
      S(I1,INC)=S(I1,INC)+CX*PLA(K)                                    013720
      S(I2,INC)=S(I2,INC)+CX*PLB(K)                                    013730
  130 IF(INA.LE.0) GO TO 150                                           013740
      S(I1,INA)=S(I1,INA)+CY*PLA(K)                                    013750
```

```
      S(I2,INA)=S(I2,INA)+CY*PLB(K)                                     013760
      GO TO 150                                                         013770
  135 CXT=CX*(HC(NC)-HC(ND))                                            013780
      CYT=CY*(HC(NA)-HC(ND))                                            013790
      VLT=VL*(HR(ND)-HC(ND))                                            013800
      IF(L1.GT.NBPAR) S(L1,IND)=S(L1,IND)+CXT                           013810
      IF(L2.GT.NBPAR) S(L2,IND)=S(L2,IND)+CYT                           013820
      IF(L3.GT.NBPAR) S(L3,IND)=S(L3,IND)+VLT                           013830
      IF(L4.GT.NBPAR) S(L4,IND)=S(L4,IND)+QRT                           013840
      IF(IND.GE.ICR) GO TO 140                                          013850
      AU(1,IND)=AU(1,IND)+E                                             013860
      AU(2,IND)=AU(2,IND)-CY                                            013870
      AU(4,IND)=AU(4,IND)-CX                                            013880
      GO TO 145                                                         013890
  140 AL(1,IND-ICR1)=AL(1,IND-ICR1)+E                                   013900
  145 B(IND)=B(IND)+QRT+VLT+CXT+CYT                                     013910
  150 CONTINUE                                                          013920
C**COMPRESS AU                                                          013930
      N=0                                                               013940
      DO 190 J=1,JD                                                     013950
      DO 190 I=1,ID                                                     013960
      N=N+1                                                             013970
      K=IN(N)                                                           013980
      IF(K.LE.0.OR.K.GE.ICR) GO TO 190                                  013990
      IF(IC(1,K).EQ.5) GO TO 190                                        014000
      IU=1                                                              014010
      IF((J-1).LT.1) GO TO 160                                          014020
      IF(IN(N-ID).LE.0) GO TO 160                                       014030
      IU=IU+1                                                           014040
      AU(IU,K)=AU(2,K)                                                  014050
  160 IF((I-1).LT.1) GO TO 170                                          014060
      IF(IN(N-1).LE.0) GO TO 170                                        014070
      IU=IU+1                                                           014080
      AU(IU,K)=AU(3,K)                                                  014090
  170 IF((I+1).GT.ID) GO TO 180                                         014100
      IF(IN(N+1).LE.0) GO TO 180                                        014110
      IU=IU+1                                                           014120
      AU(IU,K)=AU(4,K)                                                  014130
  180 IF((J+1).GT.JD) GO TO 190                                         014140
      IF(IN(N+ID).LE.0) GO TO 190                                       014150
      IU=IU+1                                                           014160
      AU(IU,K)=AU(5,K)                                                  014170
  190 CONTINUE                                                          014180
      RETURN                                                            014190
      END                                                               014200
```

```
      SUBROUTINE D4SOLVE(HC,B,IN,IC,HCA,NHCA,ID,JD,ISO)                 014210
      DIMENSION HCA(5,1100)                                             014220
      DIMENSION HC(1),B(1)                                              014230
      DIMENSION IN(1),IC(5,1)                                           014240
      DIMENSION AU(5,550),AL(30,500)                                    014250
      COMMON/INT/NIJ,NEQ,ICR,ICR1,IB1                                   014260
      COMMON/FLT/AU,AL                                                  014270
C*****ELIMINATE TO FILL AL                                              014280
                                                                        014290
      DO 280 J=1,ICR1                                                   014300
      II=IC(1,J)                                                        014310
      DO 270 I=2,II                                                     014320
      LR=IC(I,J)                                                        014330
      L=LR-ICR1                                                         014340
      C=AU(I,J)/AU(1,J)                                                 014350
      DO 260 K=I,II                                                     014360
      KL=IC(K,J)-LR+1                                                   014370
      AL(KL,L)=AL(KL,L)-C*AU(K,J)                                       014380
  260 CONTINUE                                                          014390
      AU(I,J)=C                                                         014400
      B(LR)=B(LR)-C*B(J)                                                014410
  270 CONTINUE                                                          014420
  280 B(J)=B(J)/AU(1,J)                                                 014430
C*****ELIMINATE AL                                                      014440
      JJ=NEQ-ICR                                                        014450
      DO 310 J=1,JJ                                                     014460
      JR=J+ICR1                                                         014470
      L=J                                                               014480
      DO 300 I=2,IB1                                                    014490
      L=L+1                                                             014500
      IF (AL(I,J).EQ.0.) GO TO 300                                      014510
      LR=L+ICR1                                                         014520
      C=AL(I,J)/AL(1,J)                                                 014530
      KL=0                                                              014540
      DO 290 K=I,IB1                                                    014550
      KL=KL+1                                                           014560
      IF (AL(K,J).NE.0.) AL(KL,L)=AL(KL,L)-C*AL(K,J)                    014570
  290 CONTINUE                                                          014580
      AL(I,J)=C                                                         014590
      B(LR)=B(LR)-C*B(JR)                                               014600
  300 CONTINUE                                                          014610
  310 B(JR)=B(JR)/AL(1,J)                                               014620
C*****BACK SOLVE--LOWER HALF                                            014630
      B(NEQ)=B(NEQ)/AL(1,NEQ-ICR1)                                      014640
      DO 330 J=1,JJ                                                     014650
      K=NEQ-J                                                           014660
      KL=K-ICR1                                                         014670
      L=K                                                               014680
      DO 320 I=2,IB1                                                    014690
      L=L+1                                                             014700
      IF (AL(I,KL).NE.0.) B(K)=B(K)-AL(I,KL)*B(L)                       014710
  320 CONTINUE                                                          014720
  330 CONTINUE                                                          014730
```

```
C*****BACK SOLVE--UPPER HALF                                          014740
      DO 350 J=1,ICR1                                                 014750
      K=ICR-J                                                         014760
      II=IC(1,K)                                                      014770
      DO 340 I=2,II                                                   014780
      L=IC(I,K)                                                       014790
      B(K)=B(K)-AU(I,K)*B(L)                                          014800
  340 CONTINUE                                                        014810
  350 CONTINUE                                                        014820
C*****COMPUTE HC + DELTHC                                             014830
      DO 360 N=1,NIJ                                                  014840
      L=IN(N)                                                         014850
      IF(L.LE.0) GO TO 360                                            014860
      HC(N)=HC(N)+B(L)                                                014870
  360 CONTINUE                                                        014880
C*MODIFICATION* CALCULATE NEW HEADS AT OBSERVATION POINTS              014881
      DO 370 N=1,NHCA                                                 014890
      IX=INT(HCA(1,N))                                                014900
      IY=INT(HCA(2,N))                                                014910
      I1=(IY-1)*ID+IX                                                 014920
      RESX=HCA(1,N)-IX                                                014930
      RESY=HCA(2,N)-IY                                                014940
      WA=HC(I1+1)-HC(I1)                                              014950
      WB=HC(I1+ID)-HC(I1)                                             014960
      WC=HC(I1+ID+1)+HC(I1)-HC(I1+1)-HC(I1+ID)                        014970
      WD=HC(I1)                                                       014980
  370 HCA(5,N)=WA*RESX+WB*RESY+WC*RESX*RESY+WD                        014990
      IF(ISO.GT.0)WRITE(8,900)(HCA(5,N),N=1,NHCA)                     015000
  900 FORMAT(8F10.2)                                                  015010
      RETURN                                                          015020
      END                                                             015030
```

```
      SUBROUTINE LSTSQ(HCA,HC,P,RK,PLA,PLB,S,B,IBZN,IBPA,IBPB,IN,NVE     015040
     1,NHCA)                                                             015050
      DIMENSION HC(1),P(1),RK(1),PLA(1),PLB(1),S(NVE,1),B(4)             015060
      DIMENSION HCA(5,1100),ST(50)                                       015070
      DIMENSION IBZN(1),IBPA(1),IBPB(1),IN(1)                            015080
      DIMENSION AU(5,550),AL(30,500),C(20,20)                            015090
      COMMON/INT/NIJ,NEQ,ICR,ICR1,IB1,LH1,ID,JD,IM,JM,NVAR,NQSD,NBPAR    015100
     1,NVX2,NVX3,IPO,KOUNT,INDT,IBHZ                                     015110
      COMMON/TNME/IIN,IOUT                                               015120
      COMMON/FLT/AU,AL,AP,AMP,RP,RPF,YSQ                                 015130
      EQUIVALENCE (AL(1,1),C(1,1))                                       015140
C**       CHECK FOR NONZERO MARQUARDT PARAMETER                          015150
      IF(AMP.LT.-.5) GO TO 105                                           015160
C**       INITIALIZE                                                     015170
      DO 20 J=1,NVAR                                                     015180
      DO 10 I=1,NVAR                                                     015190
   10 C(I,J)=0.                                                          015200
   20 B(J+NVX2)=0.                                                       015210
      YSQ=0.                                                             015220
      NUMSUM=0.0                                                         015230
C**       FORM COEFFICIENT MATRIX AND RIGHT-HAND SIDE VECTOR             015240
C*MODIFICATION* INTERPOLATE TO NON-NODAL HEAD OBSERVATION POINTS         015241
      DO 70 N=1,NHCA                                                     015250
      IF(HCA(4,N).LE.0.0)GO TO 70                                        015260
      IX=INT(HCA(1,N))                                                   015270
      IY=INT(HCA(2,N))                                                   015280
      RESX=HCA(1,N)-IX                                                   015290
      RESY=HCA(2,N)-IY                                                   015300
      I1=(IY-1)*ID+IX                                                    015310
      IF(RESX.NE.0.0.OR.RESY.NE.0.0)GO TO 15                             015320
      IF(IN(I1).LE.0)GO TO 70                                            015330
      DO 17 I=1,NVAR                                                     015340
   17 ST(I)=S(I,IN(I1))                                                  015350
      GO TO 16                                                           015360
   15 CONTINUE                                                           015370
      K1=IN(I1)                                                          015380
      K2=IN(I1+1)                                                        015390
      K3=IN(I1+ID)                                                       015400
      K4=IN(I1+ID+1)                                                     015410
      IF(K1.LE.0)GO TO 70                                                015420
      IF(K2.LE.0)GO TO 70                                                015430
      IF(K3.LE.0)GO TO 70                                                015440
      IF(K4.LE.0)GO TO 70                                                015450
      DO 71 I=1,NVAR                                                     015460
      WA=S(I,K2)-S(I,K1)                                                 015470
      WB=S(I,K3)-S(I,K1)                                                 015480
      WC=S(I,K4)+S(I,K1)-S(I,K2)-S(I,K3)                                 015490.
      WD=S(I,K1)                                                         015500
   71 ST(I)=WA*RESX+WB*RESY+WC*RESX*RESY+WD                              015510
   16 CONTINUE                                                           015520
C*MODIFICATION* PRINT INTERPOLATED SENSITIVITIES TO TAPE 8               015521
      IF(IPO.EQ.-1)WRITE(8,900)(ST(I),I=1,NVAR)                          015530
  900 FORMAT(8F15.5)                                                     015540
```

```
      NUMSUM=NUMSUM+1                                                   015550
      TEMP=HCA(3,N)-HCA(5,N)                                            015560
      DO 60 J=1,NVAR                                                    015570
      TMP=HCA(4,N)*ST(J)                                                015580
      DO 50 I=J,NVAR                                                    015590
   50 C(I,J)=TMP*ST(I)+C(I,J)                                           015600
   60 B(J+NVX2)=TMP*TEMP+B(J+NVX2)                                      015610
      YSQ=YSQ+TEMP*TEMP*HCA(4,N)                                        015620
   70 CONTINUE                                                          015630
      WRITE(IOUT,11)NHCA,NUMSUM                                         015640
   11 FORMAT(5X,"NHCA",I5,5X,"NUMSUM",I5)                               015650
      IF(IBHZ.LE.0) GO TO 74                                            015660
      DO 73 J=1,NIJ                                                     015670
      N=IN(J)                                                           015680
      IF(N.GE.-1.) GO TO 73                                             015690
      DO 75 I=1,NHCA                                                    015700
      IX=INT(HCA(1,I))                                                  015710
      IY=INT(HCA(2,I))                                                  015720
      I1=(IY-1)*ID+IX                                                   015730
   75 IF(I1.EQ.J)MX=I                                                   015740
      N=-N-1                                                            015750
      M=IBZN(N+NQSD)                                                    015760
      K=IBPA(M)                                                         015770
      L=IBPB(M)                                                         015780
      TMPA=PLA(N)*HCA(4,MX)                                             015790
      TMPB=PLB(N)*HCA(4,MX)                                             015800
      C(K,K)=C(K,K)+PLA(N)*TMPA                                         015810
      C(L,L)=C(L,L)+PLB(N)*TMPB                                         015820
      TMP=TMPA*PLB(N)                                                   015830
      C(K,L)=C(K,L)+TMP                                                 015840
      C(L,K)=C(L,K)+TMP                                                 015850
      TMPC=HCA(3,MX)-HC(J)                                              015860
      B(K+NVX2)=B(K+NVX2)+TMPC*TMPA                                     015870
      B(L+NVX2)=B(L+NVX2)+TMPC*TMPB                                     015880
      YSQ=YSQ+TMPC*TMPC*HCA(4,MX)                                       015890
   73 CONTINUE                                                          015900
   74 IF (NVAR.EQ.1) GO TO 190                                          015910
      DO 80 I=1,NVAR                                                    015920
      TEMP=C(I,I)+RK(I)                                                 015930
      IF(TEMP.GT.1.E-10) GO TO 78                                       015940
      WRITE(IOUT,260) I                                                 015950
      INDT=1                                                            015960
      GO TO 80                                                          015970
   78 C(I,I)=TEMP**.5                                                   015980
   80 CONTINUE                                                          015990
      IF(INDT.GT.0) RETURN                                              016000
      NM1=NVAR-1                                                        016010
      DO 100 J=1,NM1                                                    016020
      TEMP=C(J,J)                                                       016030
      JP1=J+1                                                           016040
      DO 90 I=JP1,NVAR                                                  016050
      C(I,J)=C(I,J)/(C(I,I)*TEMP)                                       016060
   90 C(J,I)=C(I,J)                                                     016070
```

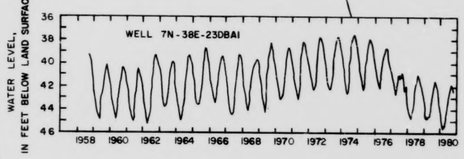
```
      B(J+NVX2)=(B(J+NVX2)+RK(J)*(P(J)-1.))/TEMP+RP*TEMP*(RPF*P(J)-1.)   016080
      B(J)=B(J+NVX2)                                                    016090
      B(J+NVX3)=TEMP                                                    016100
  100 C(J,J)=1.+RP+AMP                                                  016110
      TEMP=C(NVAR,NVAR)                                                 016120
      B(NVX3)=(B(NVX3)+RK(NVAR)*(P(NVAR)-1.))/TEMP                      016130
     1+RP*TEMP*(RPF*P(NVAR)-1.)                                         016140
      B(NVAR)=B(NVX3)                                                   016150
      B(NVAR+NVX3)=TEMP                                                 016160
      C(NVAR,NVAR)=1.+RP+AMP                                            016170
      IF(IPO.NE.1) GO TO 105                                            016180
      WRITE(IOUT,250)                                                   016190
      CALL PRTOT(C,NVE,0)                                               016200
      WRITE(IOUT,230) (B(I+NVX2),I=1,NVAR)                              016210
C********SOLVE FOR B USING LDU FACTORIZATION:                           016220
C**       DECOMPOSITION AND FORWARD SUBSTITUTION                        016230
  105 DET=1.                                                            016240
      DO 140 K=1,NM1                                                    016250
      PIV=C(K,K)                                                        016260
      DET=DET*PIV                                                       016270
      IF(ABS(PIV).GT.1.E-10) GO TO 110                                  016280
      WRITE(IOUT,210)                                                   016290
      INDT=1                                                            016300
      RETURN                                                            016310
  110 PIV=1./PIV                                                        016320
      KP1=K+1                                                           016330
      DO 130 J=KP1,NVAR                                                 016340
      TMP=C(J,K)*PIV                                                    016350
      DO 120 I=J,NVAR                                                   016360
  120 C(I,J)=C(I,J)-TMP*C(I,K)                                          016370
  130 B(J)=B(J)-TMP*B(K)                                                016380
      C(K,K)=PIV                                                        016390
  140 CONTINUE                                                          016400
      DET=DET*C(NVAR,NVAR)                                              016410
      IF(ABS(C(NVAR,NVAR)).GT.1.E-10) GO TO 150                         016420
      WRITE(IOUT,210)                                                   016430
      INDT=1                                                            016440
      RETURN                                                            016450
  150 IF(AMP.LT.-.5) RETURN                                             016460
C**       BACK SUBSTITUTION                                             016470
      B(NVX2)=B(NVAR)/C(NVAR,NVAR)                                      016480
      B(NVAR)=B(NVX2)/B(NVAR+NVX3)                                      016490
      I=NVAR                                                            016500
  160 I=I-1                                                             016510
      IF (I.LE.0) GO TO 200                                             016520
      IP1=I+1                                                           016530
      SUM=0.                                                            016540
      DO 170 J=IP1,NVAR                                                 016550
  170 SUM=SUM+C(J,I)*B(J+NVAR)                                          016560
      B(I+NVAR)=(B(I)-SUM)*C(I,I)                                       016570
      B(I)=B(I+NVAR)/B(I+NVX3)                                          016580
      GO TO 160                                                         016590
C**       SOLUTION WHEN NVAR=1                                          016600
```

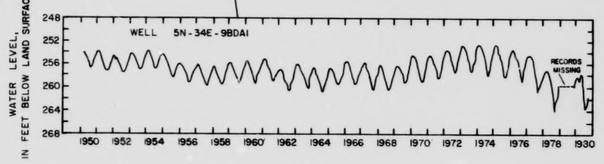
```
  190 TEMP=C(1,1)+RK(1)                                                  016610
      IF(TEMP.GT.1.E-10) GO TO 195                                       016620
      I=1                                                                016630
      WRITE(IOUT,260) I                                                  016640
      INDT=1                                                             016650
      RETURN                                                             016660
  195 B(4)=TEMP**.5                                                      016670
      B(3)=(B(3)+RK(1)*(P(1)-1.))/B(4)+RP*B(4)*(RPF*P(1)-1.)             016680
      C(1,1)=1.+RP+AMP                                                   016690
      DET=C(1,1)                                                         016700
      B(2)=B(3)/C(1,1)                                                   016710
      B(1)=B(2)/B(4)                                                     016720
C**       ADJUST AND PRINT REGRESSION COEFFICIENTS                       016730
  200 WRITE(IOUT,220) KOUNT,YSQ,DET                                      016740
      DO 202 J=1,NVAR                                                    016750
  202 B(J)=AP*B(J)                                                       016760
      WRITE(IOUT,230) (B(J),J=1,NVAR)                                    016770
      RETURN                                                             016780
C                                                                        016790
  210 FORMAT (43H0LEAST SQUARES COEFFICIENT MATRIX SINGULAR!/35H SOLUTIO016800
     1N FOR PARAMETERS NOT UNIQUE)                                       016810
  220 FORMAT (1H0,14HITERATION NO. ,I3/1H ,6HYSQ = ,E12.5,2X             016820
     1,9HDET(C) = ,E12.5/1H ,24HREGRESSION COEFFICIENTS:)                016830
  230 FORMAT ((1H ,8(E12.5,2X)))                                         016840
  250 FORMAT(49H0 SCALED LEAST SQUARES MATRIX AND GRADIENT VECTOR)       016850
  260 FORMAT (29H0SENSITIVITIES FOR PARAMETER ,I4,17H EFFECTIVELY ZERO)  016860
      END                                                                016870
```

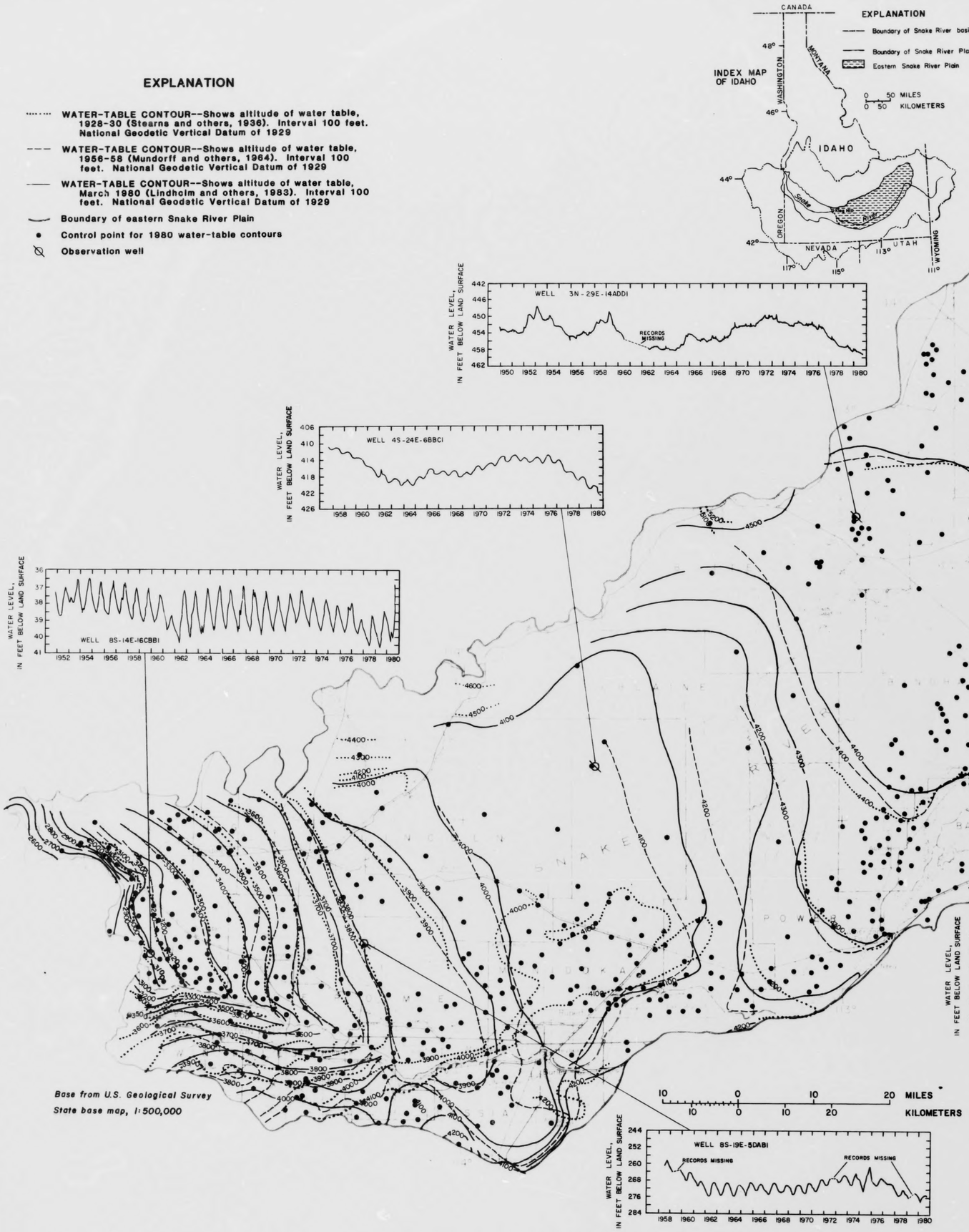
```
      SUBROUTINE PRTOT(C,NO,IT)                                          016880
C**IF IT=0, PRINT MATRICES DIVIDED VERTICALLY INTO BETWEEN ONE AND TEN P016890
C**IF IT=1, PRINT VECTOR IN THREE COLUMNS                                016900
      DIMENSION C(1)                                                     016910
      COMMON/INT/NIJ,NEQ,ICR,ICR1,IB1,LH1,ID,JD,IM,JM,NUM                016920
      COMMON/TNME/IIN,IOUT                                               016930
      IF(IT.EQ.1) GO TO 25                                               016940
      ITMP=(NUM-1)/10+1                                                  016950
      IB=1                                                               016960
      DO 20 IBK=1,ITMP                                                   016970
      INC=IBK*10                                                         016980
      IF(NUM.LT.INC) INC=NUM                                             016990
      WRITE(IOUT,30) (I,I=IB,INC)                                        017000
      WRITE(IOUT,50)                                                     017010
      K=-NO                                                              017020
      DO 10 J=1,NUM                                                      017030
      K=K+NO                                                             017040
   10 WRITE(IOUT,40) J,(C(I+K),I=IB,INC)                                 017050
      WRITE(IOUT,60)                                                     017060
      IB=INC+1                                                           017070
   20 CONTINUE                                                           017080
      RETURN                                                             017090
   25 NR=NO/3                                                            017100
      IF((3*NR).NE.NO) NR=NR+1                                           017110
      DO 26 K=1,NR                                                       017120
   26 WRITE(IOUT,80) (L,C(L),L=K,NO,NR)                                  017130
      RETURN                                                             017140
C                                                                        017150
   30 FORMAT (1H0,8X,I3,9(9X,I3))                                        017160
   40 FORMAT (1H ,I3,10(1X,E11.4))                                       017170
   50 FORMAT (1H )                                                       017180
   60 FORMAT (1H0)                                                       017190
   80 FORMAT(1H ,3X,3(I3,5X,E11.4,5X))                                   017200
      END                                                                017210
```

EXPLANATION

- WATER-TABLE CONTOUR--Shows altitude of water table, 1928-30 (Stearns and others, 1936). Interval 100 feet. National Geodetic Vertical Datum of 1929
- WATER-TABLE CONTOUR--Shows altitude of water table, 1956-58 (Mundorff and others, 1964). Interval 100 feet. National Geodetic Vertical Datum of 1929
- WATER-TABLE CONTOUR--Shows altitude of water table, March 1980 (Lindholm and others, 1983). Interval 100 feet. National Geodetic Vertical Datum of 1929
- Boundary of eastern Snake River Plain
- Control point for 1980 water-table contours
- Observation well



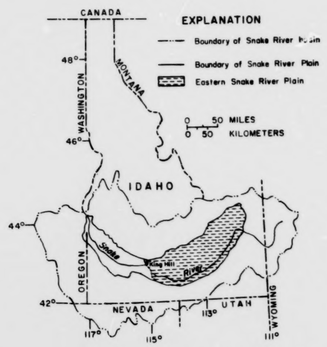




CONFIGURATION OF THE WATER TABLE, 1928-30, 1956-58, AND MARCH 1980; AND HYDROGRAPHS OF SELECTED WELLS, EASTERN SNAKE RIVER PLAIN, IDAHO

EXPLANATION

- Inactive node
- 12 — Aquifer zone boundary and number
- 2.9 — Boundary flux, in cubic feet per second
- Leakage block
- WATER-TABLE CONTOUR--Shows altitude of water table, March 1980. Interval 100 feet. National Geodetic Vertical Datum of 1929
- Boundary of eastern Snake River Plain



INDEX MAP OF IDAHO

Water-table contours modified from Lindholm and others, 1988

Base from U.S. Geological Survey
State base map, 1:500,000

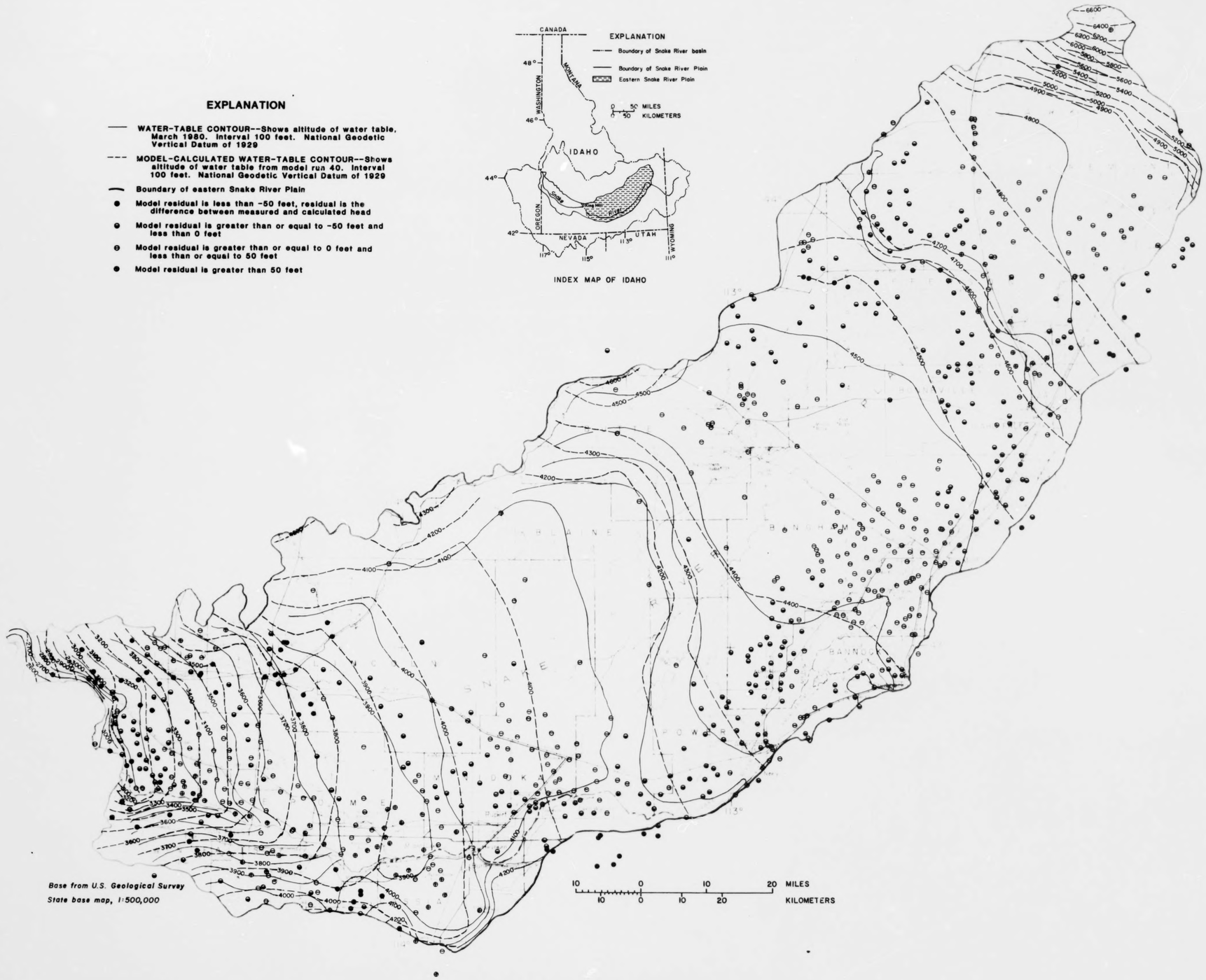
10 0 10 20 MILES
10 0 10 20 KILOMETERS

GROUND-WATER FLOW MODEL GRID, AQUIFER ZONES, LEAKAGE BLOCKS, AND BOUNDARY FLUX, EASTERN SNAKE RIVER PLAIN, IDAHO

EXPLANATION

- WATER-TABLE CONTOUR--Shows altitude of water table, March 1980. Interval 100 feet. National Geodetic Vertical Datum of 1929
- MODEL-CALCULATED WATER-TABLE CONTOUR--Shows altitude of water table from model run 40. Interval 100 feet. National Geodetic Vertical Datum of 1929
- Boundary of eastern Snake River Plain
- Model residual is less than -50 feet, residual is the difference between measured and calculated head
- Model residual is greater than or equal to -50 feet and less than 0 feet
- Model residual is greater than or equal to 0 feet and less than or equal to 50 feet
- Model residual is greater than 50 feet

INDEX MAP OF IDAHO



CONFIGURATION OF THE WATER TABLE, MARCH 1980, COMPARED WITH CONFIGURATION BASED ON MODEL-CALCULATED HEADS, EASTERN SNAKE RIVER PLAIN, IDAHO